Appendix A

Documentation of the Analytica Models

Decision Insights, Inc.

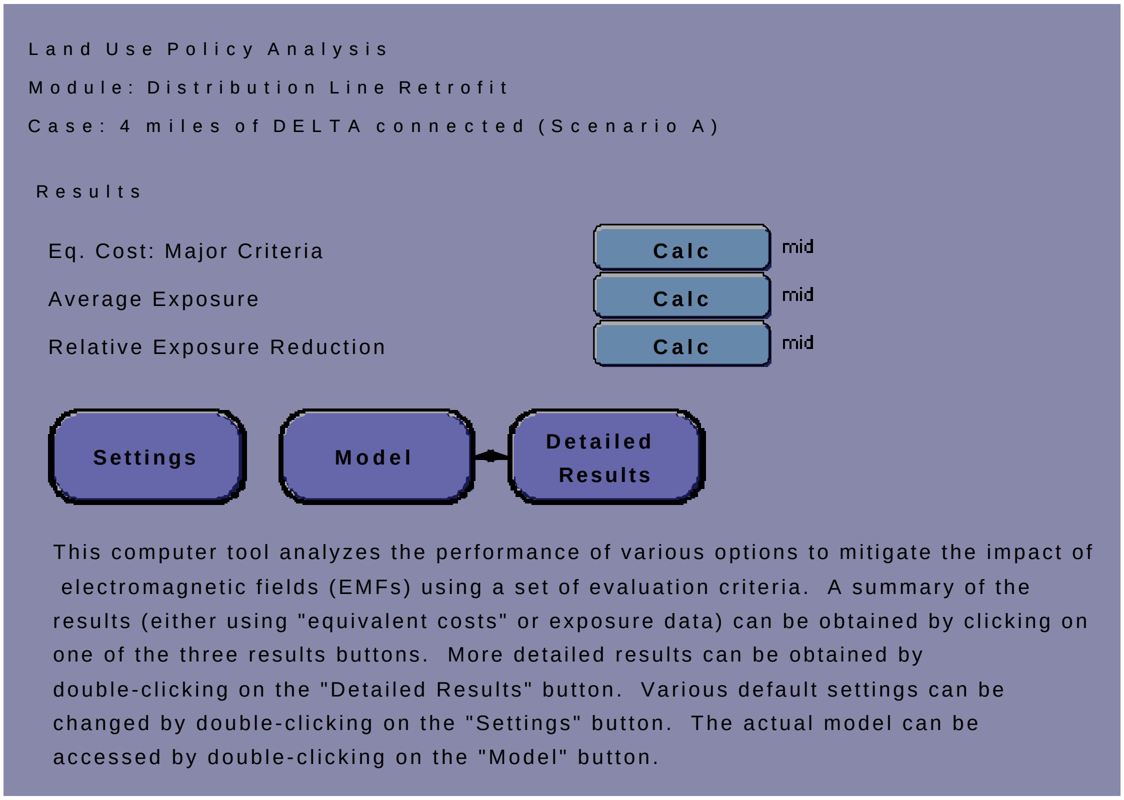
Part I:

Transmission and Distribution Line Models

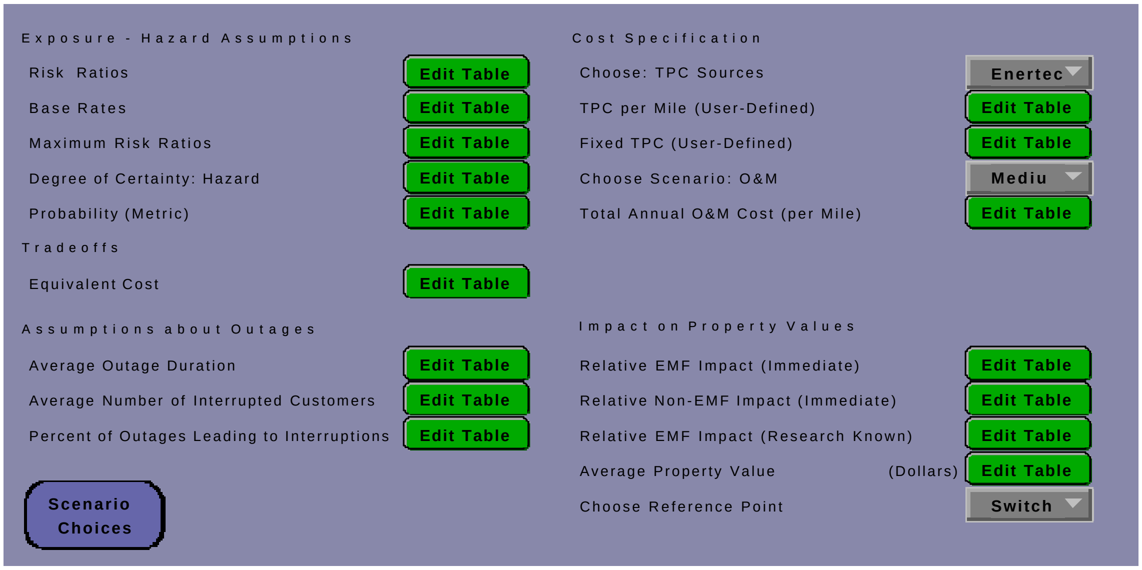
Introduction

This documentation describes the screens, key user variables, input parameters, and estimates for the Analytica models developed as part of the "Power Grid and Land Use Policy Analysis." The documentation follows the screen-shots of Analytica. Part I of this documentation is for the models addressing transmission and distribution lines. Part II is for the home grounding models. The documentation can also be found in each Analytica model by clicking any node in the model and then clicking the question mark button at the top of the Analytica screen.

The hardcopy of this documentation is for the "DR-A.ana" Analytica model only. While the documentation is fairly generic and most of the materials apply to all models, some specific items will differ between models. In particular, each model has a different structure and a different set of estimates for "Total Project Cost."


Land Use Policy Analysis
Module: Distribution Line Retrofit
Case: 4 miles of DELTA connected (Scenario A)
Results
Eq. Cost: Major Criteria
Calc
mid
Average Exposure
Calc
mid
Relative Exposure Reduction
Calc
mid
Settings
Model
Detailed Results
This computer tool analyzes the performance of various options to mitigate the impact of electromagnetic fields (EMFs) using a set of evaluation criteria. A summary of the results (either using "equivalent costs" or exposure data) can be obtained by clicking on one of the three results buttons. More detailed results can be obtained by double-clicking on the "Detailed Results" button. Various default settings can be changed by double-clicking on the "Settings" button. The actual model can be accessed by double-clicking on the "Model" button.

Settings



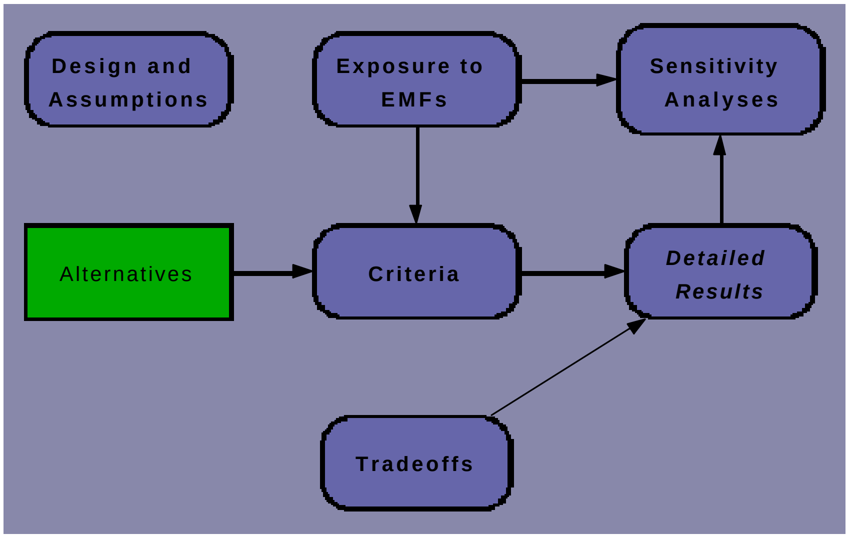
Settings

In the **"Settings"** menu**,** the user can make many changes to the key model parameters related to assumptions about the EMF hazard, outages, costs, and impacts on property values. These changes are usually made in edit tables or by choosing from a low, medium, and high scenario. An important choice is whether to use cost estimates provided by Enertech Consultants (1998 a and b) or user specified cost estimates. By setting the reference point for impacts on property values, the user can also determine whether to treat property impacts as gains (e.g., by undergrounding) or as costs (e.g., by not undergrounding).

Enertech Consultants. Electric and Magnetic Field Exposure Assessment of Powerline and Non-Powerline Sources for Public School Environments. DRAFT, October 1998a.

Enertech Consultants, Magnetic Field Mitigation Cost Estimates, DRAFT, June 1998b.

Model

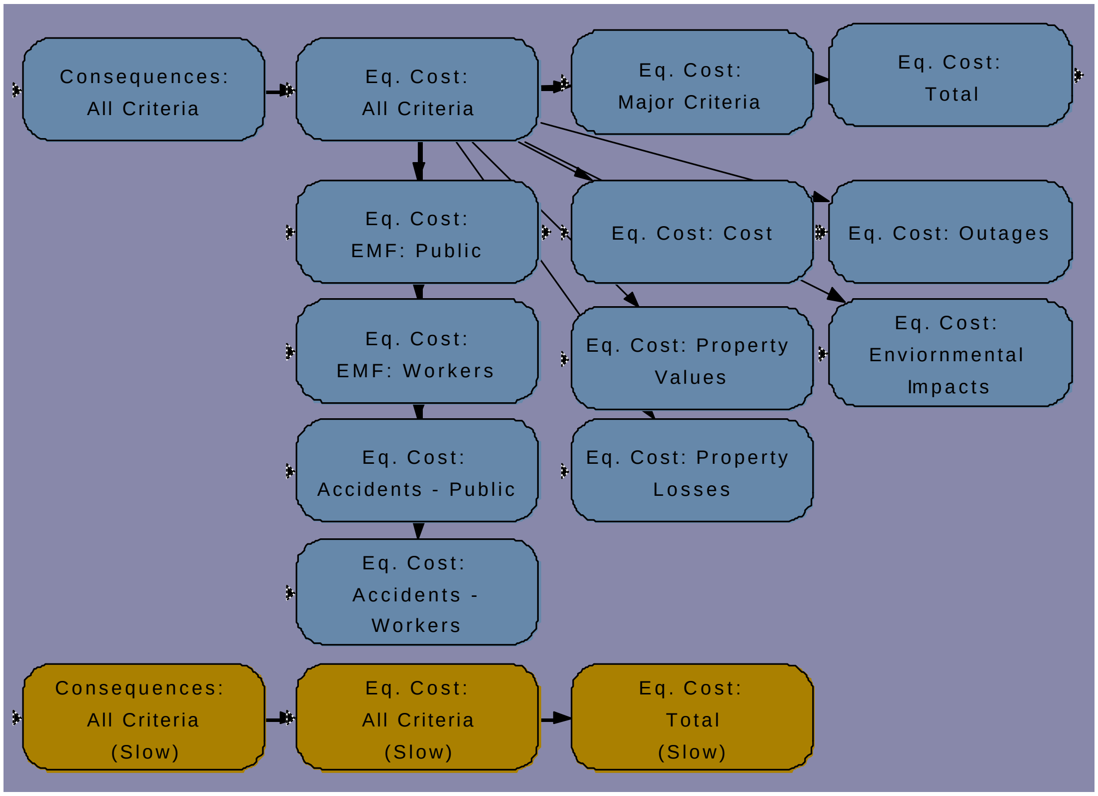


Model

Each Power Grid and Land Use Policy Analysis has the following building blocks: **"Exposure to EMFs," "Alternatives,"** and **"Criteria."** In addition, **"Design and Assumptions"** and **"Tradeoffs"** are defined to produce **"Detailed Results."** The exposure data are imported from a model developed in C++ by Jack Adams with a Visual Basic interface developed by Thomas Eppel (see Decision Insights, Inc., 1999). Exposures are imported as an array defined by a) the segment of the line, b) the mitigation measure, c) the effects function, and d) the distance from the line**.** **"Alternatives"** are land use and engineering options to reduce EMFs. They are defined both in the Analytica models and in the exposure model. The **"Alternatives"** are evaluated on the **"Criteria,"** for example on public health risks due to EMF or on total project cost. To evaluate the alternatives on the criteria, models are used, which are sometimes quite complex. To access the models, the user can double-click on the **"Criteria"** node and continue through the relevant sub-menus. The **"Design and Assumptions"** node contains a menu of basic inputs that define the mitigation, land use, and population characteristics of the scenario as well as key parameters that are used throughout the model. The **"Tradeoffs"** are defined as unit equivalent costs for each criterion. For example the (default) tradeoff for one person-year life lost is $100,000. **"Sensitivity Analyses"** allow the user to vary the degree of certainty of a hazard and the risk ratios used in the model over a wide range to show how sensitive the decision is to variations in these parameters.

Decision Insights, Inc. Power Grid and Land Use Policy Analysis. DRAFT, April, 1999

Detailed Results



Detailed Results

This diagram lets the user examine the results of the model at many different levels, ranging from the consequences, expressed in the natural units of the criteria (**"Consequences: All Criteria"**) to various equivalent costs of subsets of the criteria and consequences. For example, the user can take a quick look at the **"Eq. Cost: Major Criteria,"** which typically are public health, direct dollar cost (including total project cost, operations and maintenance, and power losses), and property values. In some analyses, noise and disruption and outages also become major criteria. The equivalent costs are the consequences in their natural units multiplied by the unit equivalent cost defined in **"Tradeoffs."** The yellow nodes access results for all scenario combinations, not just for the ones specified by the user. Running the model in the "yellow" mode will substantially increase the total calculation time.

Model – Design and Assumptions

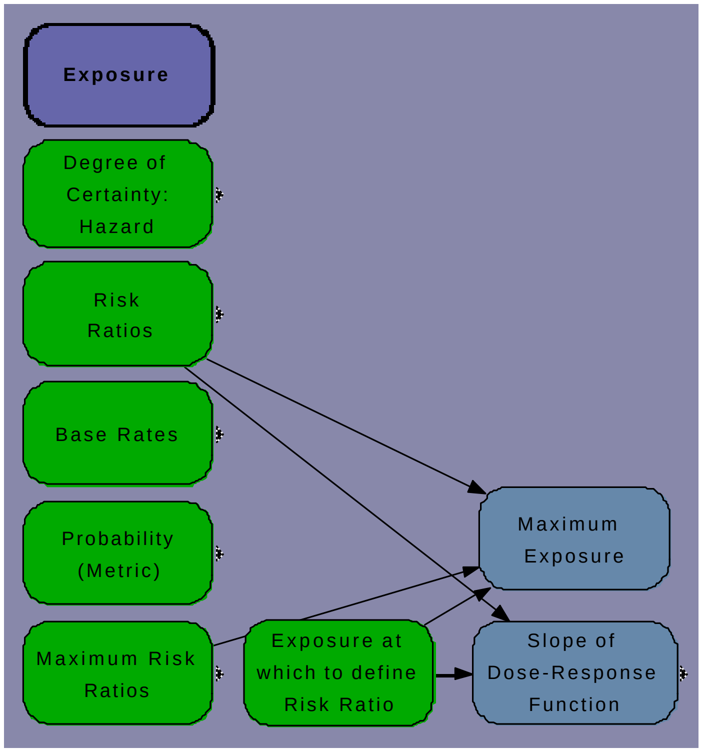
Design and Assumptions

CAUTION: THIS MENU IS FOR ADVANCED USERS ONLY. WE RECOMMEND THAT USERS OBTAIN TRAINING IN THE USE OF THE ANALYTICA MODELS PRIOR TO MAKING ANY CHANGES IN THIS MENU.

This menu lets users create new scenarios. In particular, it lets users specify **"Alternatives, Line Design, Land Use,"** including mitigation alternatives, line segments and cells, width of a cell, width of a sub-cell, exposure exclusion zones (e.g., ROWs), and population characteristics. Segments, cells, and sub-cells are defined in the node **"Exposure."** In addition, several **"Basic Specifications of the Model"** related to the property values of EMF, power loss, aesthetic impact, construction activities, and costs must be specified. These basic specifications will have to be changed, if any of the **"Alternatives, Line Design, and Land Use"** items have been changed. **"Other Assumptions"** include various constants that are used throughout the model. These constants will typically not be changed.

This menu is for advanced users of the Analytica models only. It is intended to create new scenarios efficiently. However, the user needs to know which changes require re-running the exposure model (e.g., changing cell and sub-cell width or creating new mitigation options) or alter other parts of the model. The following changes can be made without rerunning the exposure model or making other changes in the Analytica model: Applying different mitigation alternatives for a given segment of the line (**"Mitigation by Alternative"**); changing the length of a segment; increasing or decreasing exclusion zones; changing population densities, homes, and adult-children percentages; and all **"Basic Specifications of the Model."** However, other changes, such as changing the width of a cell or the width of the sub-cell require re-running the exposure model or resetting basic specifications of the Analytica model.

Model –- Exposure



Exposure

This model picks up the exposure data and calculates a dose-response. The dose response function is defined through **"Risk Ratios"** anchored a selected **"Exposures at which to define Risk Ratios"** and a **"Maximum Risk Ratio"** that puts a ceiling to the response in the dose response functions. Dose-response functions are defined separately for different exposure metrics. To provide all the necessary inputs to calculate incremental risks, the model uses "Base Rates" from readily available statistics, and a user defined **"Probability (Metric)."** The **"Degree of Certainty: Hazard"** is another user defined input that in effect works as a discount factor on the calculated incremental risk.

Degree of Certainty: Hazard

This item specifies the probability that EMF exposure poses a health hazard. When users adjust it, they should keep in mind that the probability attached to a degree of seriousness of the hazard defined by the risk ratios (see below). Thus, for example, one user may think that there is a high probability of a hazard, but that the incremental risk would be extremely small. In this case the probability of a hazard may be 0.50, but the risk ratios may be 1.1. Another user may think that the probability of a hazard is small, but that the incremental risk is high. In this case the probability of a hazard may be 0.05, but the risk ratios may be 4.

IT IS IMPORTANT TO ASSESS THE DEGREE OF A HAZARD IN CONNECTION WITH THE RISK RATIOS, OTHERWISE IMPLAUSIBE RISK ESTIMATES CAN OCCUR.

Risk Ratios

"Risk Ratios" are defined as the risk with EMF exposure at 2mG TWA (or equivalent medium exposures for other metrics) divided by the base rate risk, assuming that EMF exposure poses a hazard. For example, some epidemiological studies of childhood leukemia show approximately a 50% elevated risk around 2mG exposure, which corresponds to a risk ratio of 1.5. The risk ratios are defined separately for each health endpoint to account for the epidemiological findings (Decision Insights, 1999). For the linear threshold (LT) metrics the risk ratio defined at 2mG TWA was used to extrapolate the risk ratios at values above the threshold. For the binary threshold metrics the risk ratios at 2mG TWA were applied to 50% exceedances (2mG threshold), 20% exceedances (5 mG threshold), and 10% exceedances (10 mG threshold). Following are the risk ratios at 2 mG TWA estimated from the epidemiological literature (Decision Insights, 1999):

Alzheimer's Disease: 2
Adult Brain Cancer: 1.5
Adult Leukemia: 2
Adult Breast Cancer: 1.5
Childhood Leukemia: 1.5
Childhood Brain Cancer: 1.5

Decision Insights, Power Grid and Land Use Policy Analysis, Draft, 1999.

Exposure at which to define Risk Ratios

The user can choose a different set of exposure levels at which the risk ratios are defined. For example, a user may want to define the risk ratios at 3 or 5 mG or at different percentage exceedance levels. If this option is taken, we recommend that the user revisit all risk ratios and maximum risk ratios to make sure that the combinations are plausible.

Maximum Risk Ratios

If one would extrapolate the risk ratios linearly to high exposures, certain anomalies would occur. For example, a risk ratio of 2 at 2mG TWA would be extrapolated linearly to a risk ratio of about 100 at 200mG. This seems unreasonable, considering that the highest risk ratios in epidemiological EMF research have been around 5-10 (studies in other health areas have found risk ratios as high as 20). It is therefore more reasonable to define an upper bound of the risk ratio, using epidemiological evidence, and to use this upper bound to provide a limit to the dose-response function. The following **"Maximum Risk Ratios"** were defined based on epidemiological studies (see Decision Insights, 1999):

Alzheimer's Disease: 4
Adult Brain Cancer: 2
Adult Leukemia: 2
Adult Breast Cancer: 2
Childhood Leukemia: 3
Childhood Brain Cancer: 3

Decision Insights, Power Grid and Land Use Policy Analysis, Final Report, 1999.

Base Rates

The "Base Rates" for the six health endpoints considered in the model were obtained from two sources: American Cancer Society (1998) and the Center for Disease Control (1998):

Alzheimer's Disease: 0.005
Adult Brain Cancer – Fatal: 0.000067
Adult Brain Cancer – Nonfatal: 0.000087
Adult Leukemia – Fatal: 0.00011
Adult Leukemia – Nonfatal: 0.00014
Breast Cancer – Fatal: 0.00022 (females only)
Breast Cancer – Nonfatal: 0.00089 (females only)
Childhood Brain Cancer – Fatal: 0.000005
Childhood Brain Cancer – Nonfatal: 0.0000075
Childhood Leukemia – Fatal: 0.00002
Childhood Leukemia – Nonfatal: 0.00003

American Cancer Society, Cancer Facts and Figures, Web Site: www.cancer.org/statistics, 1998.

Center for Disease Control, Faststats: Alzheimer's Disease, Web Site: www.cdc.nchswww/fastats/alzheimr.htm, 1998.

Center for Disease Control, Faststats: Leading Causes of Death, Web Site: www.cdc.nchswww/fastats/cancer, 1998.

Center for Disease Control, Faststats: Leading Causes of Death, Web Site: www.cdc.nchswww/fastats, 1998.

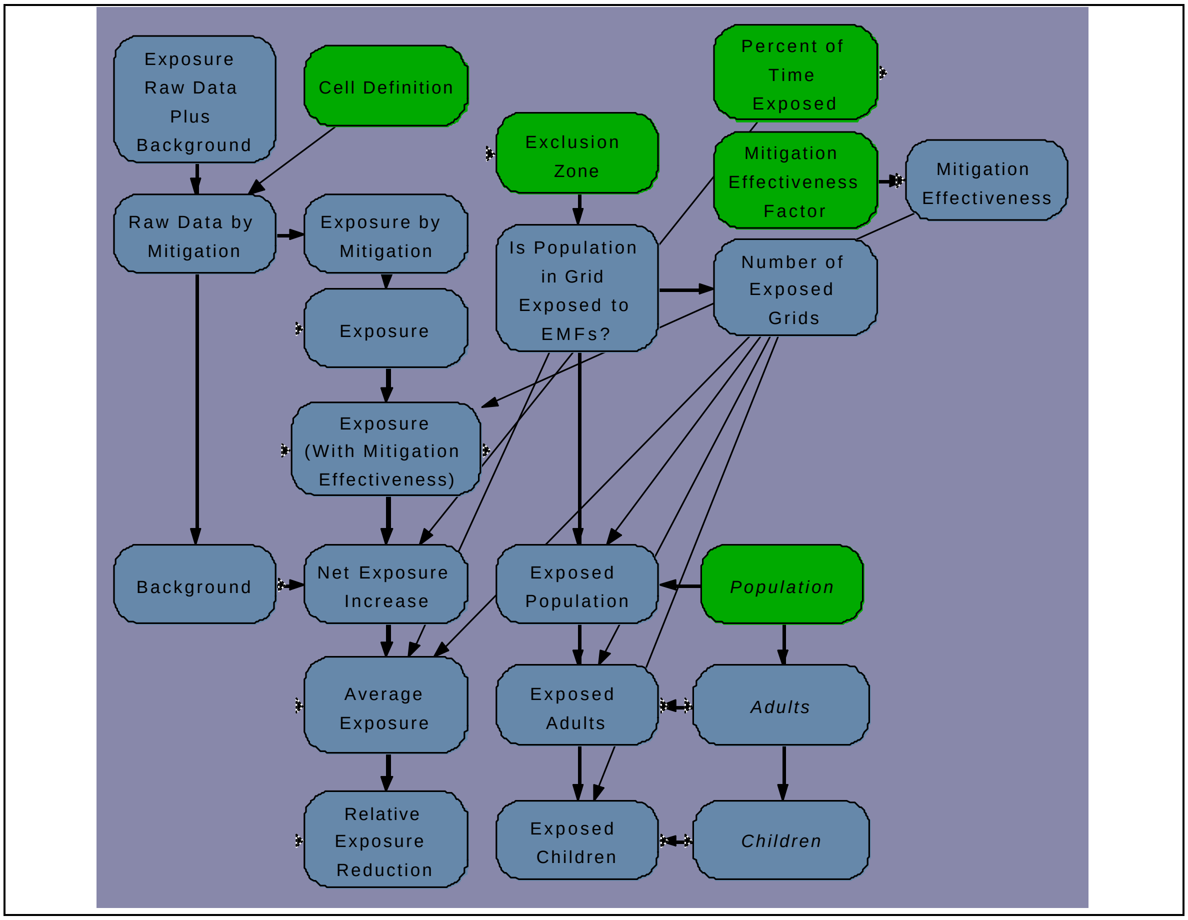
Probability (Metric)

The models have seven possible exposure metrics and one "other" metric. The seven are:

1. Time-weighted average
2. Linear threshold at 2 mG
3. Linear threshold at 5 mG
4. Linear threshold at 10 mG
5. Binary threshold at 2 mG
6. Binary threshold at 5 mG
7. Binary threshold at 10 mG

The user can assign probabilities to these metrics or "pick" one metric by assigning a probability of 1. The default setting is a probability of 1 for the TWA metric.

Model – Exposure – Exposure

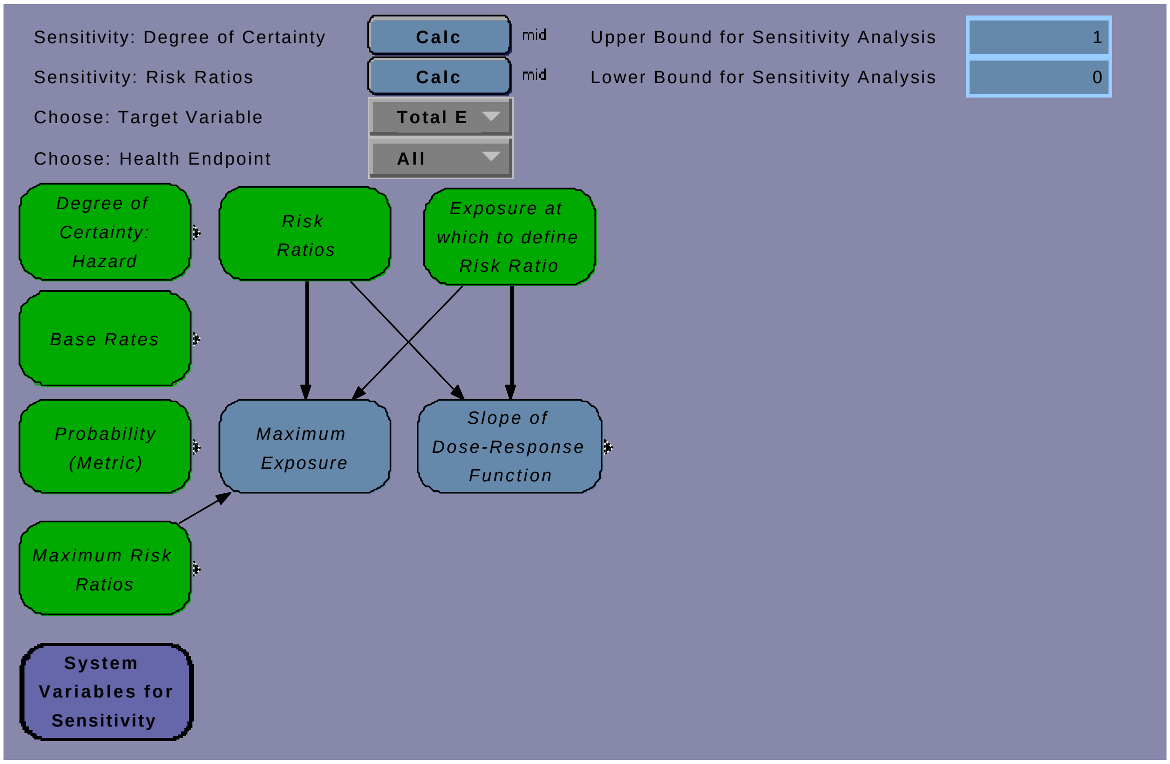


Exposure

This model reads in the **"Exposure Raw Data Plus Background"** from Jack Adam's exposure simulation model. This is an array of exposure data defined by a) mitigation measures, b) effects functions, c) different segments, and d) distances from the line. A segment is a piece of the line. A cell is a rectangle with the length of the segment and a width that is defined as a distance from the line where exposures will approach background exposure (usually 300-500 feet). Cells are also indexed by the mitigation measure. Cells are the key building blocks in both Jack Adam's exposure model and in the Analytica model. Cells are further subdivided into sub-cells which are rows of fixed width (usually ten feet) paralleling the line.

The model lets the user define **"Exclusion Zones,"** such as the Right-of-Way, as sub-cells without people and thus no exposure. Exclusion zones are the main mechanism to model land use alternatives. Through **"Mitigation Effectiveness"** users can define, how likely they think that a mitigation measure is effective in reducing EMF risks. This variable captures the idea that the "real" exposure metric is not captured in the model. While the mitigation measure is effective in reducing exposures on the modeled metrics, it may not be effective in reducing exposures on the relevant, yet unknown metric. The default value for **"Mitigation Effectiveness"** is 100%. The density of the **"Population"** and the percentage of **"Adults"** and **"Children"** can be defined separately for each segment. The user can also specify the percent of time people are exposed in each cell, considering, for example land use (schools, offices, etc.). The default value is 100%. The **"Net Exposure Increase"** is determined by subtracting the **"Background"** exposure. Combining the "Net Exposure Increase" with the "Exposed Population" the model then calculates the **"Average Exposure"** for each mitigation alternative and the **"Relative Exposure Reduction"** due to mitigation.

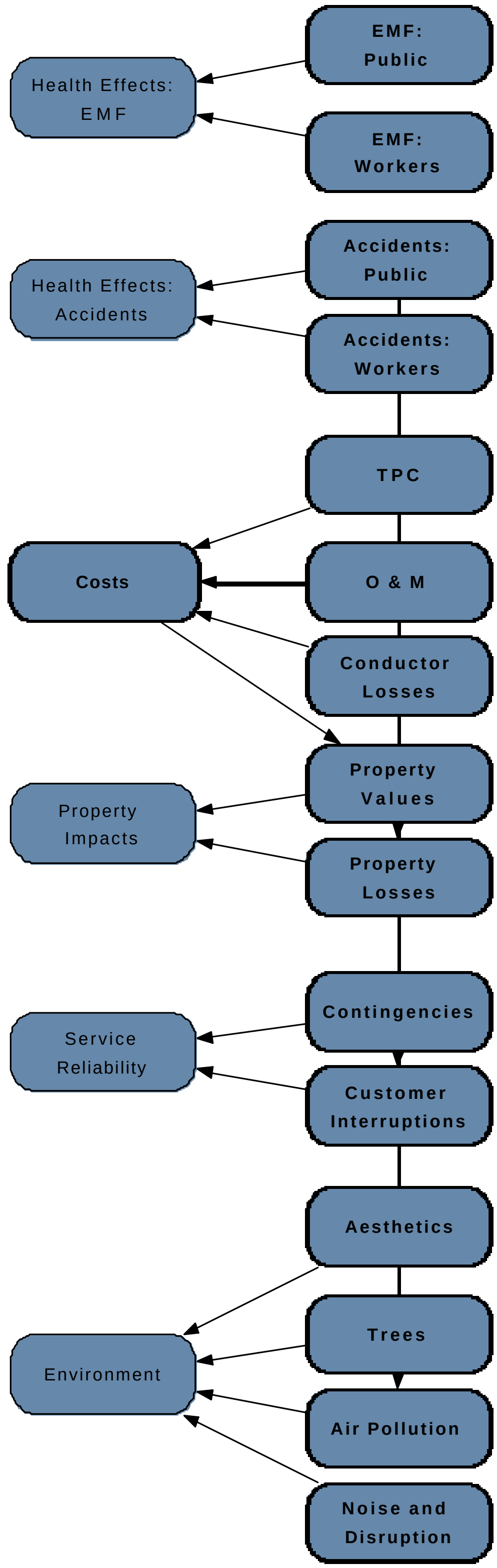
Model – Sensitivity Analyses



Sensitivity Analyses

This menu lets the user access sensitivity analyses on the **"Degree of Certainty: Hazard**" and on the **"Risk Ratios"** for different health endpoints and different target variables. Other sensitive parameters like the **"Probability (Metric)"** or the **"Maximum Risk Ratios"** can be varied as well in this menu.

Model – Criteria

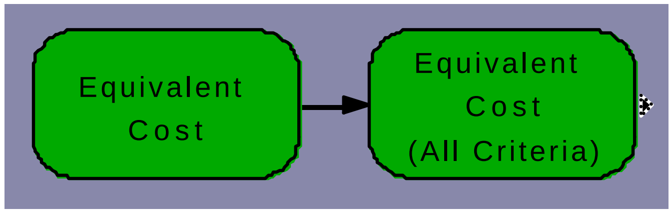


Criteria

These 15 criteria are used to evaluate the engineering and land use alternatives in the Power Grid and Land Use Policy Analysis. Some criteria (EMF-Public, EMF-Workers, Accidents-Public, Accidents-Workers, and Property Losses) have multiple sub-criteria.

To estimate the performance of the engineering or land use alternatives, models were developed for each criterion or sub-criterion. To access these models, the user needs to simply double-click on the criteria or sub-criteria.

Model - Tradeoffs



Tradeoffs

Equivalent cost tradeoffs are defined for units of all criteria in the model, in order to make the consequences on different criteria commensurable.

The literature on the value of life and injuries was used to define default values (see, for example, Jones-Lee, 1976; Thaler and Rosen, 1975; Howard, 1980; Viscusi, 1992, 1993; Tengs, 1995). In addition, a recent interview with five national researchers familiar with the risk tradeoff literature (Keeney and von Winterfeldt, 1997) was used to calibrate the tradeoffs. Other values were estimated based on common sense reasoning. The default values are:

One Year of Life-Expectancy Lost: $100,000
One Non-Fatal Cancer (Adult): $300,000
One Non-Fatal Cancer (Child): $500,000
One Alzheimer's Disease: $200,000
One Serious Injury: $10,000
One Contingency Hour: $10,000
One Person-Hour of Electricity Disruption: $10
One Pole Collision (Property Damage): $10,000
One Lost Tree: $1,000
One Person-Day of Noise and Disruption: $10
One Unit on Aesthetics Scale: $10,000

Jones-Lee, M.W. The value of life: An economic analysis. Chicago: Chicago University Press, 1976.

Howard, R. On making life and death decisions. In R.C. Schwing and W.R. Alberts (eds.) Societal risk assessment. New York, Plenum Press, 1980, 89-106.

Tengs, T., et al. Five hundred life-savings intervention and their cost-effectiveness. Risk Analysis, 15, 3, 1995, 369-390.

Thaler, R. and Rosen, S. The value of saving a life: Evidence from the labor market. In Terleckyi, N.E. (ed.) Household production and consumption. New York: Columbia University Press, 1975, 265-298.

Viscusi, W,K. Fatal tradeoffs. New York: Oxford University Press, 1992.

Viscusi, W.K. The value of risks to life and health. Journal of Economic Literature, 312, 1993, 1912-1946.

Keeney, R.L. and von Winterfeldt, D. Value tradeoffs for the Hanford tank waste remediation system program. Report No. PNNL-11724, UC-630. Ricjland, WA: Pacific Northwest National Laboratory, 1997.

Model – Alternatives

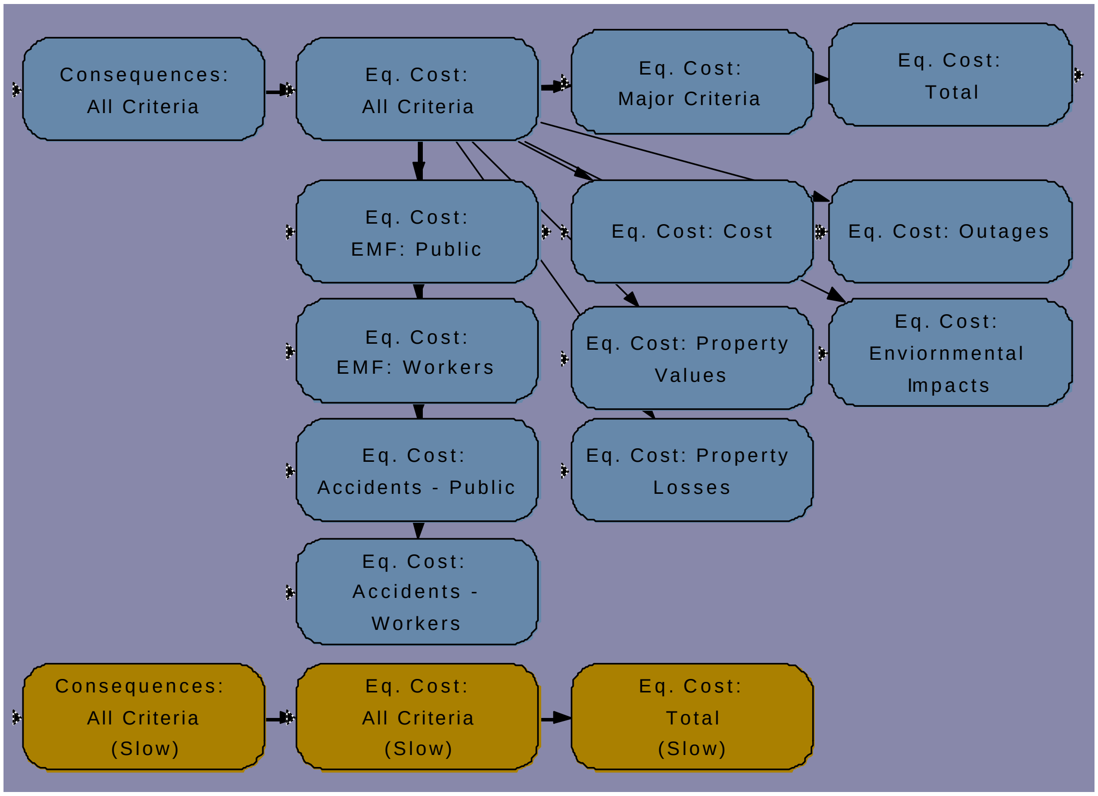
Alternatives

Alternatives are mitigation measures (engineering or land use) assigned to each segment of the line. For example, in scenario A of the distribution line model, the following mitigation measures were considered

1. No change to the line
2. Compact delta configuration
3. Raising pole height
4. Undergrounding

In this scenario the line had 4 one-mile segments. An example alternative was to underground the line in each segment. Another alternative was to underground the line only in the segment closest to the substation.

Model – Detailed Results



Detailed Results

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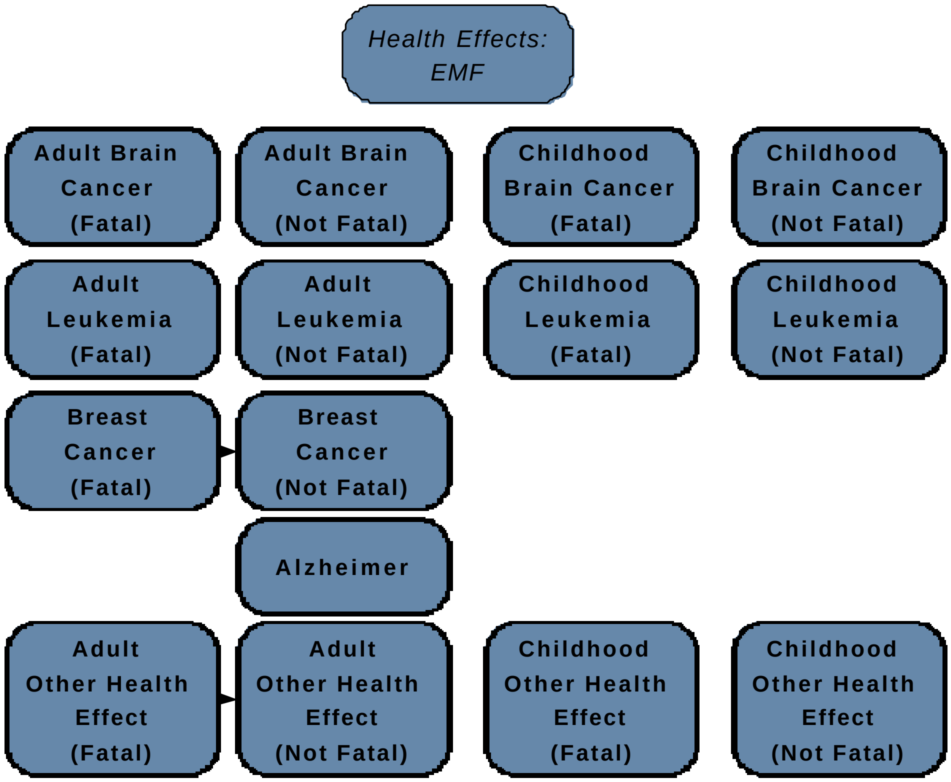
Model – Criteria – EMF: Public

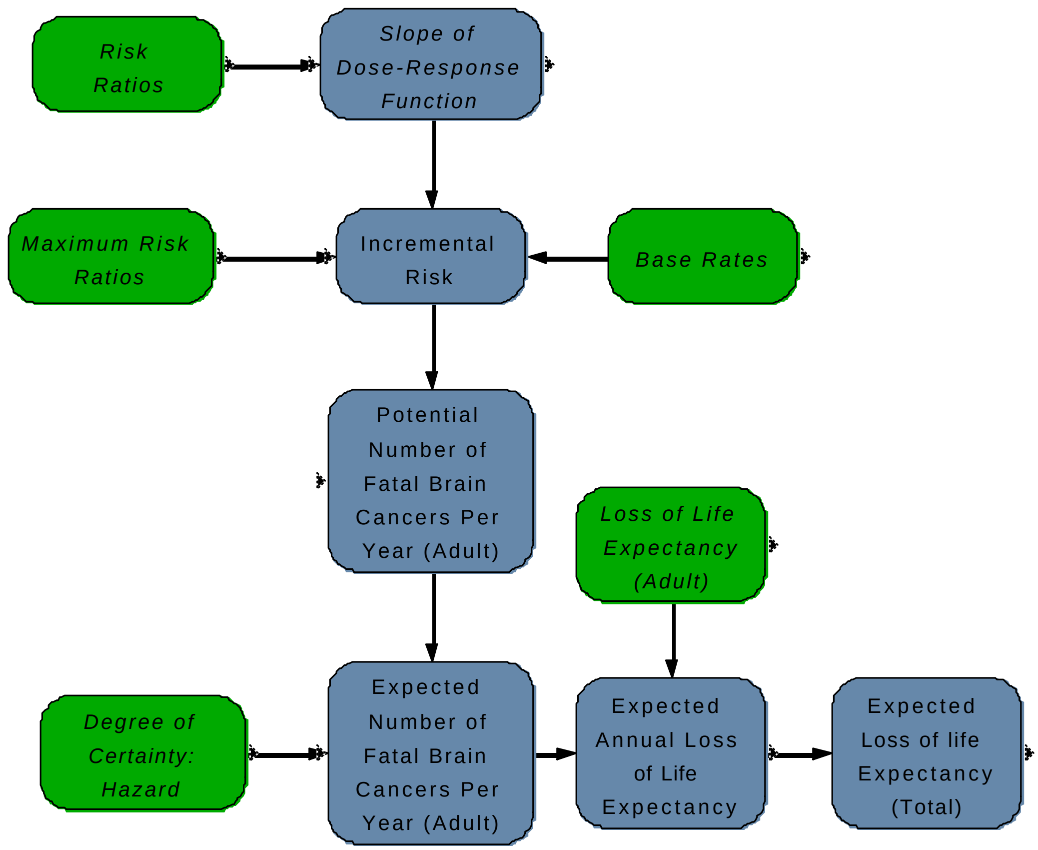


EMF: Public

The criterion **"EMF: Public**" is divided into 15 sub-criteria. Key distinctions are the health endpoints (leukemia, brain cancer, breast cancer, and Alzheimer's disease), fatal vs. non-fatal health effects for cancers, and whether children or adults are affected. Alzheimer's disease is counted and evaluated as a long-term disease, not as a one-time cause of death. In addition, the user can supply the information for an unspecified health endpoint by using the four nodes for fatal and non-fatal **"Other Health Effects"** for children and adults. The health risk models are very similar across these health endpoints, as illustrated for the criterion **"Adult Brain Cancer (Fatal)."**

Model – Criteria – EMF Public – Adult Brain Cancer (Fatal)

(Same Documentation for All Health Endpoints)



Cancer (Fatal or Nonfatal)

This diagram shows how the **"Expected Loss of Life Expectancy (Total)"** is calculated. The **"Risk Ratios"** and **"Maximum Risk Ratios"** are used to create dose-response functions, separately for each health endpoint. This is done as follows. The user inputs **"Risk Ratios"** that characterize, separately for each health endpoint, the increase in risk at 2mG (or equivalent "medium" exposure for other metrics), assuming that EMF is a hazard. This input defines one point of the dose-response function. The other point is defined by a risk ratio of 1 at zero mG exposure (or 0% exceedances of a threshold). From this information, the model calculates the slope of a linear dose-response function (the intercept being at RR=1, Exposure=0). The user also specifies the **"Maximum Risk Ratio,"** which is defined as the maximum factor by which risk can plausibly be increased, if one assumes that EMF is a hazard. This input provides an upper limit for the risk ratios and defines an exposure, above which the risk ratio is held constant at its upper limit.

Using the input from Jack Adams' exposure model, the **"Slope of the Dose-Response Function,"** and the **"Base Rates"** for each health endpoint, the model then calculates **"Incremental Risk"** in terms of annual fatality or illness rate due to the line. This incremental risk is multiplied by the number of people exposed to determine the "**Potential Number of Fatal** (or Nonfatal) **Cancers per Year,"** separately for Adults and Children, assuming that there is a hazard. The "**Expected Number of Fatal** (or Nonfatal) **Cancers per Year"** are then calculated by multiplying the **"Potential Number of Fatal** (or Nonfatal) **Cancers per Year"** by the **"Degree of Certainty: Hazard,"** which specifies the probability that EMF exposure poses a hazard. In the case of Alzheimer's disease, the model considers only the incidence rate and calculates the **"Expected Number of Annual Alzheimer Cases."**

For fatal cancers, the "**Expected Number of Fatal Cancers"** are multiplied with the average "**Loss of Life Expectancy"** to determine an **"Expected Annual Loss of Life Expectancy."** This annual loss is multiplied by the lifetime of the line (default: 35 years) to calculate the "**Expected Loss of Life Expectancy (Total)"**.
For nonfatal cancers, the **"Expected Number of Non-Fatal Cancers Per Year"** are multiplied by the lifetime of the line (default: 35 years) to calculate the **"Expected Number of Nonfatal Cancers (Total)."** Alzheimer's disease is treated like a non-fatal cancer.

Risk Ratios

"Risk Ratios" are defined as the risk with EMF exposure at 2mG TWA (or equivalent medium exposures for other metrics) divided by the base rate risk, assuming that EMF exposure poses a hazard. For example, some epidemiological studies of childhood leukemia show approximately a 50% elevated risk around 2mG exposure, which corresponds to a risk ratio of 1.5. The risk ratios are defined separately for each health endpoint to account for the epidemiological findings (Decision Insights, 1999). For the linear threshold (LT) metrics the risk ratio defined at 2mG TWA was used to extrapolate the risk ratios at values above the threshold. For the binary threshold metrics the risk ratios at 2mG TWA were applied to 50% exceedances (2mG threshold), 20% exceedances (5 mG threshold), and 10% exceedances (10 mG threshold). Following are the risk ratios at 2 mG TWA estimated from the epidemiological literature (Decision Insights, 1999):

Alzheimer's Disease: 2
Adult Brain Cancer: 1.5
Adult Leukemia: 2
Adult Breast Cancer: 1.5
Childhood Leukemia: 1.5
Childhood Brain Cancer: 1.5

Decision Insights, Power Grid and Land Use Policy Analysis, Draft, 1999.

Maximum Risk Ratios

If one would extrapolate the risk ratios linearly to high exposures, certain anomalies would occur. For example, a risk ratio of 2 at 2mG TWA would be extrapolated linearly to a risk ratio of about 100 at 200mG. This seems unreasonable, considering that the highest risk ratios in epidemiological EMF research have been around 5-10 (studies in other health areas have found risk ratios as high as 20). It is therefore more reasonable to define an upper bound of the risk ratio, using epidemiological evidence, and to use this upper bound to provide a limit to the dose-response function. The following **"Maximum Risk Ratios"** were defined based on epidemiological studies (see Decision Insights, 1999):

Alzheimer's Disease: 4
Adult Brain Cancer: 2
Adult Leukemia: 2
Adult Breast Cancer: 2
Childhood Leukemia: 3
Childhood Brain Cancer: 3

Decision Insights, Power Grid and Land Use Policy Analysis, Final Report, 1999.

Base Rates

The "Base Rates" for the six health endpoints considered in the model were obtained from two sources: American Cancer Society (1998) and the Center for Disease Control (1998):

Alzheimer's Disease: 0.005
Adult Brain Cancer – Fatal: 0.000067
Adult Brain Cancer – Nonfatal: 0.000087
Adult Leukemia – Fatal: 0.00011
Adult Leukemia – Nonfatal: 0.00014
Breast Cancer – Fatal: 0.00022 (females only)
Breast Cancer – Nonfatal: 0.00089 (females only)
Childhood Brain Cancer – Fatal: 0.000005
Childhood Brain Cancer – Nonfatal: 0.0000075
Childhood Leukemia – Fatal: 0.00002
Childhood Leukemia – Nonfatal: 0.00003

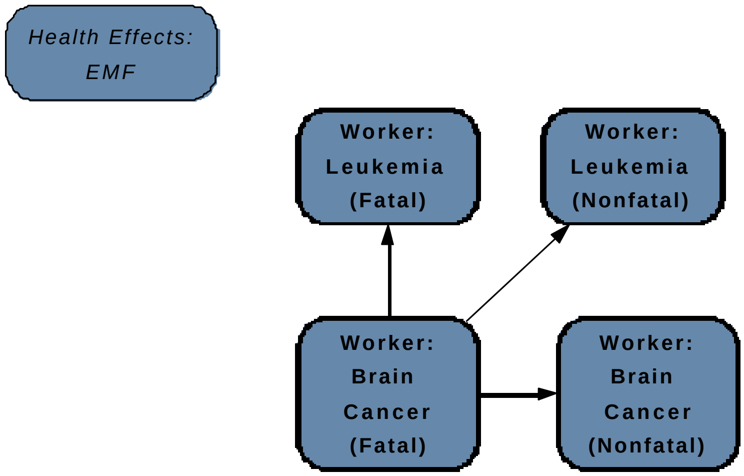
American Cancer Society, Cancer Facts and Figures, Web Site: www.cancer.org/statistics, 1998.

Center for Disease Control, Faststats: Alzheimer's Disease, Web Site: www.cdc.nchswww/fastats/alzheimr.htm, 1998.

Center for Disease Control, Faststats: Leading Causes of Death, Web Site: www.cdc.nchswww/fastats/cancer, 1998.

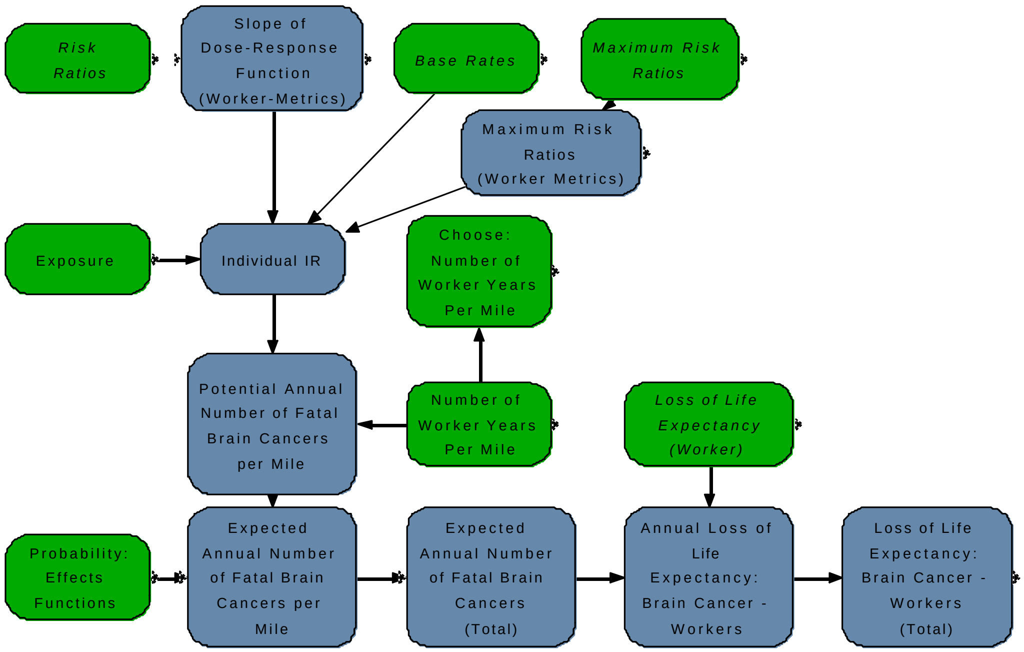
Center for Disease Control, Faststats: Leading Causes of Death, Web Site: www.cdc.nchswww/fastats, 1998.

Model – Criteria – EMF: Workers



EMF: Workers
This model considers the risks of fatal and non-fatal brain cancer and leukemia for utility linemen.

Model – Criteria – EMF: Workers – Fatal Brain Cancer
(Same Documentation for All Health Endpoints)



EMF: Workers – Fatal Brain Cancer

This model estimates the fatal brain cancers of utility linemen due to exposures to EMF. It combines **"Exposure"** estimates from the epidemiological literature with the dose response function developed for adult brain cancer (see EMF: Public – Adult Brain Cancer (Fatal)). Based on the **"Number of Worker Years per Mile"** of line and assuming that EMF is a hazard, the exposure estimate and dose-response function combine to determine the **"Potential Annual Number of Fatal Brain Cancers per Mile."** Using the probability that there is a hazard and the selected effects function, the **"Expected Annual Number of Fatal Brain Cancers per Mile"** can be calculated. This result is extrapolated for the total miles of the line and converted into **"Annual Loss of Life Expectancy: Brain Cancer Workers."** This annual estimate is multiplied by the lifetime of the line (default: 35 years) to calculate the **"Loss of Life Expectancy: Brain Cancer – Workers (Total). "**

Exposure

The “Exposure” node contains default values for linemen while working on live lines. The numbers are expressed in milliGauss (mG) TWA and in percent exceedances of thresholds. The estimates are from Bracken et al. (1990) and Theriault et al. (1994). Bracken et al. (1990) do not distinguish between underground and overhead work, but they have an extensive database that was used to calibrate exposure from lines. The data by Theriault et al. (1994) suggest that underground live work involves about twice the average exposure than overhead line work. As a first approximation, the model uses Bracken et al. (1990) data to estimate overhead exposure and multiplies it by 2 to estimate underground exposure:

Overhead, average exposure: 2 mG
Overhead, > 2 mG: 50%
Overhead, > 5 mG: 25%
Overhead, >10 mG: 10%

Underground, average exposure: 4 mG
Underground, > 2 mG: 100%
Underground, > 5 mG: 50%
Underground, > 10 mG: 20%

Bracken , D. et al. The EMDEX Project: Technology Transfer and Occupational Measurements. EPRI EN 7048, Palo Alto: Electric Power Research Institute, 1990.

Theriault, G. et al. Cancer risks associated with occupational exposure to magnetic fields among utility workers in Ontario and Quebec, Canada and France, 1970-1989. American Journal of Epidemiology, 139, 550-570, 1994.

Risk Ratios

“Risk Ratios” are defined as the risk with EMF exposure at 2mG TWA divided by the base rate risk, assuming that EMF exposure poses a hazard. For example, some epidemiological studies of childhood leukemia show approximately a 50% elevated risk around 2mG exposure, which corresponds to a risk ratio of 1.5. The risk ratios are defined separately for each health endpoint to account for the epidemiological findings (Decision Insights, 1999). For the linear threshold (LT) metrics the risk ratio defined at 2mG TWA was used to extrapolate the risk ratios at values above the threshold. For the binary threshold metrics the risk ratios at 2mG TWA were applied to 50% exceedances (2mG threshold), 20% exceedances (5 mG threshold), and 10% exceedances (10 mG threshold). Following are the risk ratios at 2 mG TWA estimated from the epidemiological literature (Decision Insights, 1999):

Alzheimer’s Disease: 2
Adult Brain Cancer: 1.5
Adult Leukemia: 2
Adult Breast Cancer: 1.5
Childhood Leukemia: 1.5
Childhood Brain Cancer: 1.5

Decision Insights, Power Grid and Land Use Policy Analysis, Final Report, 1999.

Maximum Risk Ratios

If one would extrapolate the risk ratios linearly to high exposures, certain anomalies would occur. For example, a risk ratio of 2 at 2mG TWA would be extrapolated linearly to a risk ratio of about 100 at 200mG. This seems unreasonable, considering that the highest risk ratios in epidemiological EMF research have been around 5-10 (studies in other health areas have found risk ratios as high as 20, but never as high as 100). It is therefore more reasonable to define an upper bound of the risk ratio, using epidemiological evidence, and to use this upped bound to provide a limit to the dose-response function. The following **"Maximum Risk Ratios"** were defined based on epidemiological studies (see Decision Insights, 1999):

Alzheimer's Disease: 4
Adult Brain Cancer: 2
Adult Leukemia: 2
Adult Breast Cancer: 2
Childhood Leukemia: 3
Childhood Brain Cancer: 3

Decision Insights, Power Grid and Land Use Policy Analysis, Final Report, 1999.

Base Rates

The "Base Rates" for the six health endpoints considered in the model were obtained from two sources: American Cancer Society (1998) and the Center for Disease Control (1998):

Alzheimer's Disease: 0.005
Adult Brain Cancer – Fatal: 0.000067
Adult Brain Cancer – Nonfatal: 0.000087
Adult Leukemia – Fatal: 0.00011
Adult Leukemia – Nonfatal: 0.00014
Breast Cancer – Fatal: 0.00022 (females only)
Breast Cancer – Nonfatal: 0.00089 (females only)
Childhood Brain Cancer – Fatal: 0.000005
Childhood Brain Cancer – Nonfatal: 0.0000075
Childhood Leukemia – Fatal: 0.00002
Childhood Leukemia – Nonfatal: 0.00003

American Cancer Society, Cancer Facts and Figures, Web Site: www.cancer.org/statistics, 1998.

Center for Disease Control, Faststats: Alzheimer's Disease, Web Site: www.cdc.nchswww/fastats/alzheimr.htm, 1998.

Center for Disease Control, Faststats: Leading Causes of Death, Web Site: www.cdc.nchswww/fastats/cancer, 1998.

Center for Disease Control, Faststats: Leading Causes of Death, Web Site: www.cdc.nchswww/fastats, 1998.

Number of Worker-Years per Mile

First, the total miles of overhead and underground transmission and distribution lines of one major California utility was determined:

OH-TL: 18,409
OH-DL: 180,000
UG-TL: 108
UG- DL: 40,000

Second, a consultant to DII (Gray, 1998) estimated the number of transmission and distribution linemen in this utility:

Transmission Linemen: 50 (low), 75 (medium), 100 (high)
Distribution Linemen: 3000 (low), 3250 (medium), 3500 (high)

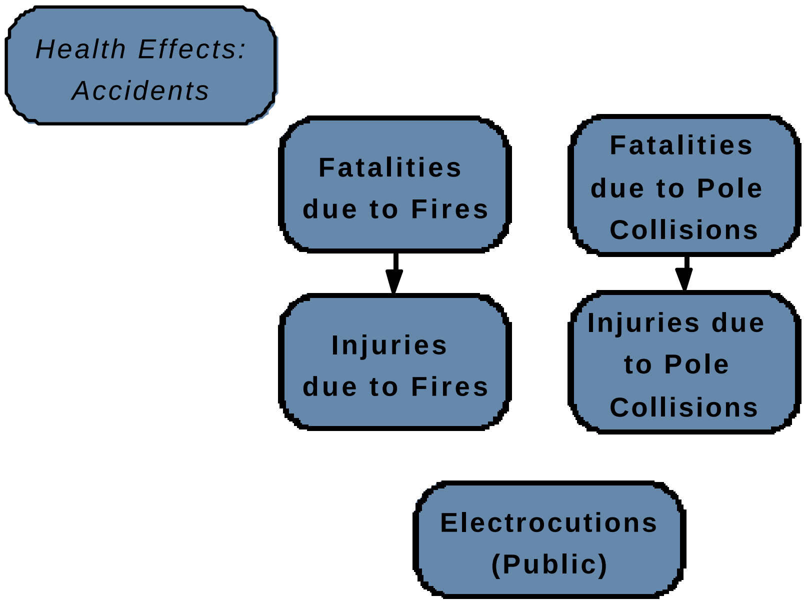
Third, the same consultant estimated the percentage of time that workers would work at or near energized lines:

Transmission: 1% (low), 2.5% (medium), 5% (high)
Distribution: 10% (low), 20% (medium), 30% (high)

This information was used to calculate first the total worker-years spent at or near energized lines, and second, to calculate the worker-years per mile of transmission and distribution lines:

Transmission: 0.000027 (low); 0.0001 (medium); 0.0003 (high)
Distribution: 0.0014 (low); 0.003 (medium); 0.0048 (high).

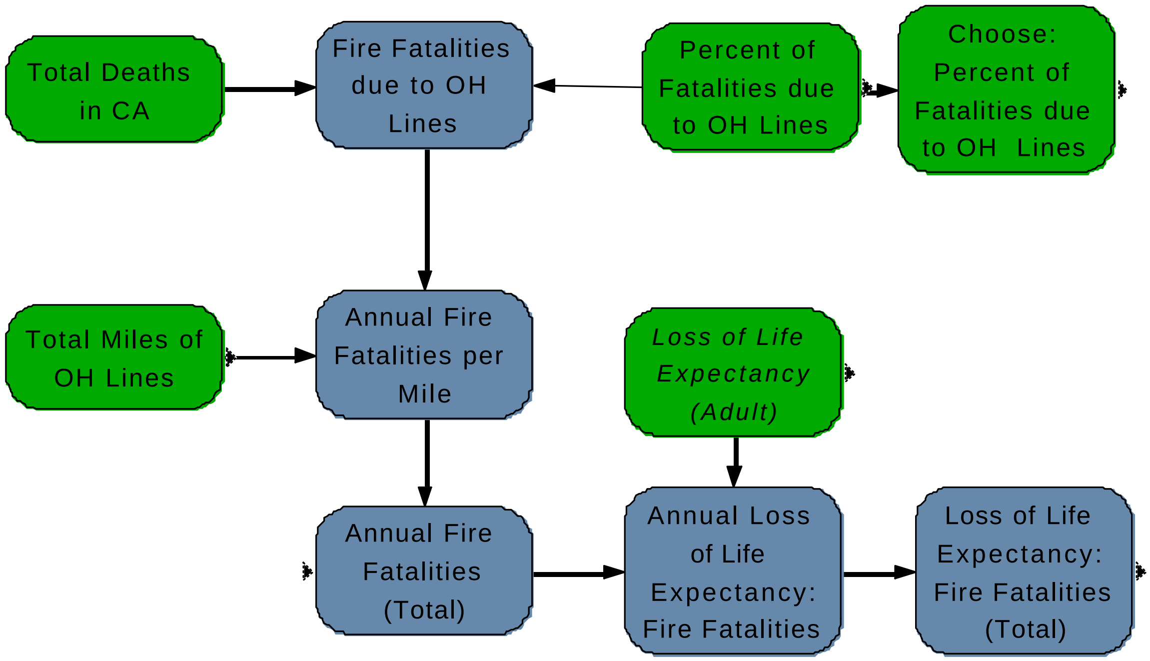
Model – Criteria - Accidents: Public



Accidents: Public

This model calculates the estimated deaths and injuries due to three causes: fires from transmission or distribution lines, automobile collisions with powerline poles, and electrocutions due to contact with transmission or distribution lines. For electrocutions, only fatalities were considered.

Model – Criteria – Accidents: Public - Fatalities due to Fires



Fatalities (Injuries) due to Fires

This model calculates the **"Annual Fire Fatalities (Injuries) per Mile"** of overhead transmission and distribution lines in California. The key numbers in this calculation is **"Total Deaths in CA"** due to fires - an average of 319 deaths (and about 5,000 injuries) per year for a ten year period in the eighties (California State Fire Marshal, 1988). The **"Percent of Fatalities due to OH Lines"** is very uncertain. We used conservative estimates. The combination of total deaths (or injuries) and percent due to overhead lines, combined with the **"Total Miles of OH Lines,"** results in an estimate of the **"Annual Fire Fatalities per Mile."** The remaining calculations are based on separate segments of a line and using a loss of life expectancy of 35 years for a fatality.

California State Fire Marshall. California Fire Incident Reporting System: Annual Report, 1988. Sacramento: CSFM, 1988.

Total Deaths (Injuries) in California

This single valued input is the total annual fire deaths (injuries) in California. Using a ten-year average from 1979 to 1988, the default value is 319 deaths and 5,000 injuries per year (California State Fire Marshal, 1988).

California State Fire Marshall. California Fire Incident Reporting System: Annual Report, 1988. Sacramento: CSFM, 1988.

Percent of Fatalities (Injuries) due to OH Lines

According to the National Fire Data Center (1978) about 11% of all fires are due to electrical distribution. This includes overhead and underground transmission and distribution. It is unclear whether this percentage includes wiring in buildings, but the 11% figure is certainly close to an upper bound for the percentage of fires due to distribution and transmission lines. We further assume that all fires are due to overhead (OH) lines, none to underground (UG) lines and that the percent of fires is identical to the percent of fatalities (injuries).

To reflect the uncertainties in the estimation of this percentage, the user can use three settings:

Low: 1%
Medium: 5%
High: 11%

National Fire Data Center. Fire in the United States. Washington, DC: U.S. Department of Commerce, 1978.

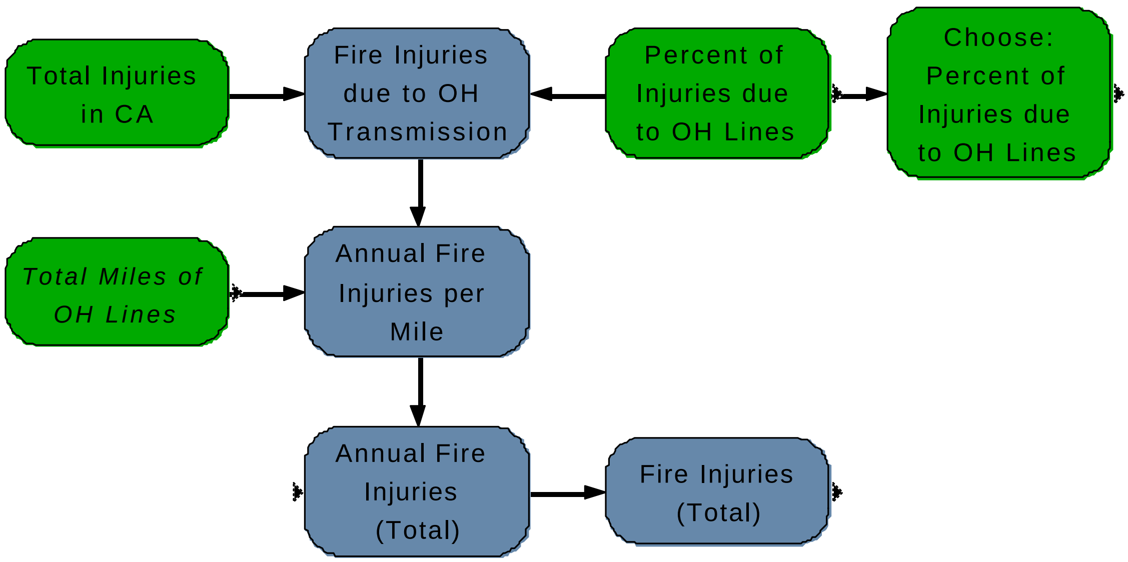
Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Model – Criteria – Accidents: Public - Injuries due to Fires



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To reflect the uncertainties in the estimation of this percentage, the user can use three settings:

Low: 1%
Medium: 5%
High: 15%

National Fire Data Center. Fire in the United States. Washington, DC: U.S. Department of Commerce, 1978.

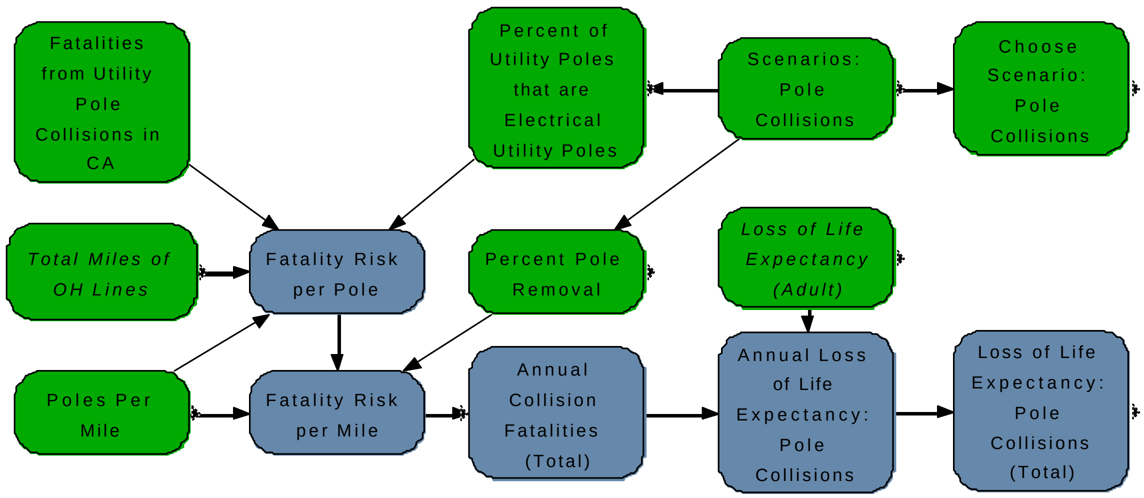
Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Model – Criteria – Accidents: Public – Fatalities due to Pole Collisions



Fatalities due to Pole Collisions

This model estimates fatalities and the associated loss of life expectancy due to utility pole collisions. The key variable is "**Fatality Risk per Pole**." It depends on the "**Fatalities from Utility Pole Collisions in California (CA)**," the "**Percent of Utility Poles that are Electrical Utility Poles**," the "**Total Miles of Overhead (OH) Transmission and Distribution System**," and the "**Number of Poles per Mile**."

The "**Fatality Risk per Mile"** for overhead design is the product of the fatality risk per pole times the number of poles per mile. The "**Fatality Risk per Mile"** for undergrounding an existing overhead line is the residual risk, once the poles for overhead distribution are removed. If all poles are removed, this residual risk is zero. However, some poles may remain, to support existing structures or non-electrical utilities.

Fatalities from Utility Pole Collisions in CA

Between 1994 and 1997 there were, on average 126 automobile crashes with utility pole collisions in California, with 69 fatalities, 49 injuries, and 8 cases with property damage only (see below).

	1994	1995	1996	1997	Average
Fatal	75	69	63	68	**69**
Injury	53	39	58	44	**49**
No Injury	15	10	5	3	**8**
TOTAL	**143**	**118**	**126**	**115**	**126**

Fatal Accident Reporting System (FARS), 1994, 1995, 1996, 1997. US Department of Transportation, National Highway Safety Administration. FARS Web Site: www-fars.nhtsa.dot.gov, FARS Query System, February, 1999.

Percent of Utility Poles that are Electrical Utility Poles

The U.S. Department of Transportation FARS data distinguishes between light posts, sign posts, and utility posts, but it does not distinguish between electrical and other utility posts (telephone and cable). However, one can assume that most utility posts are electrical utility poles or poles that carry multiple utility lines. The user can choose between three values: Low (80%), Medium (90%), and High (100%).

Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Percent Pole Removal

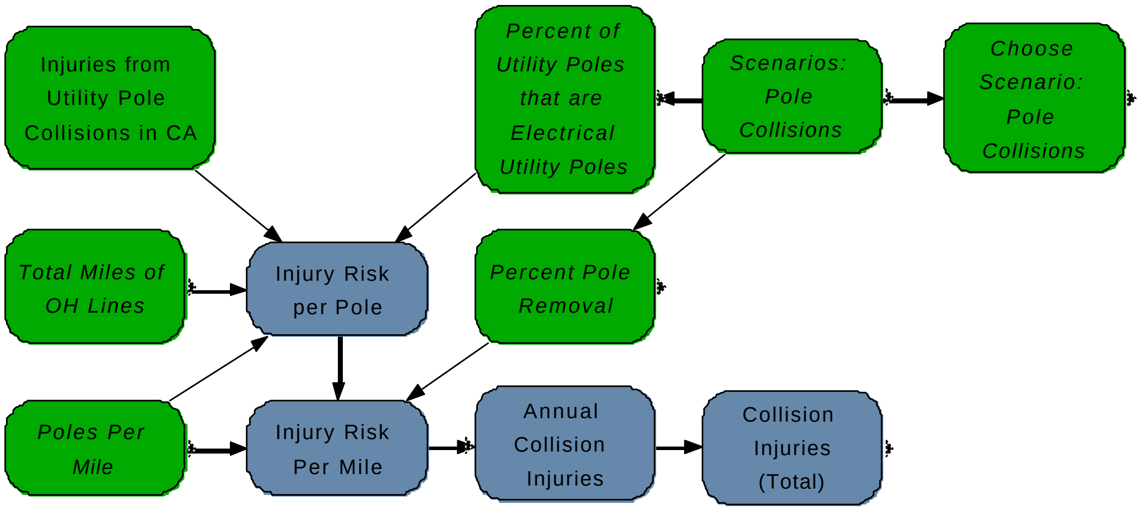
Not all poles will necessarily be removed when an overhead line is undergrounded. For example, poles that carry street lights will either remain to provide light, or they will be replaced by light poles. The model lets the user choose between 50% (low), 75% (medium) and 100% (high) pole removal.

Poles Per Mile

The number of poles can vary as a function of the weight of the line and other factors from 10 per mile to 20 per mile. As a default, the model uses 20 poles per mile.

William Gray, Consultant to Decision Insights, Inc. Personal communication, August, 1998.

Model – Criteria – Accidents: Public – Injuries due to Pole Collisions



Injuries due to Utility Pole Collisions

This model estimates injuries due to utility pole collisions. The key variable is "**Injury Risk per Pole**." It depends on the "**Injuries from Utility Pole Collisions"** in California (CA), the "**Percent of Utility Poles that are Electrical Utility Poles**," the "**Total Miles of OH Lines**," and the "**Number of Poles per Mile**."

The "**Injury Risk per Mile"** for overhead design is the product of the injury risk per pole times the number of poles per mile. The "**Injury Risk per Mile"** for undergrounding an existing overhead line is the residual risk, once the poles for overhead distribution are removed. If all poles are removed, this residual risk is zero. However, some poles may remain, to support existing structures or non-electrical utilities.

Injuries from Utility Pole Collisions

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Percent of Utility Poles that are Electrical Utility Poles

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Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

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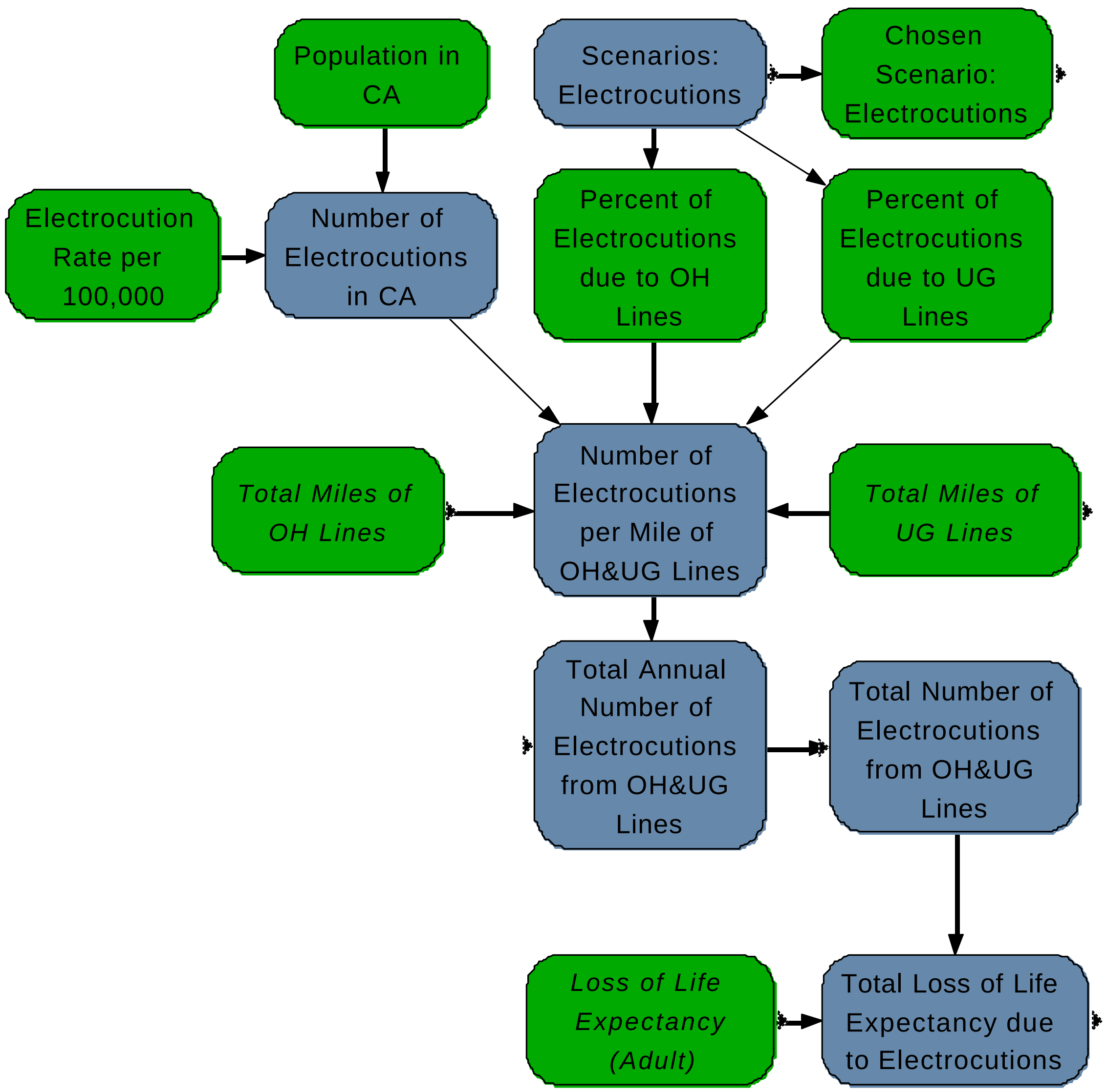
Poles Per Mile

The number of poles can vary as a function of the weight of the line and other factors from 10 per mile to 20 per mile. As a default, the model uses 20 poles per mile.

Source: William Gray, Consultant to Decision Insights, Inc. Personal communication, August, 1998.

Model – Criteria – Accidents: Public – Electrocutions



Electrocutions (Public)

This model builds on the "**Electrocution Rate per 100,000"** population in the U.S. (about 0.30) and calculates the "**Number of Electrocutions in CA"** by multiplying the rate by 300 (assuming 30 million people in California). It then allocates a percentage of this number to overhead lines and to underground lines. Using the respective **"Total Miles of OH (UG) Lines,"** the model then normalizes the resulting electrocutions to a "**Number of Electrocutions per Mile of OH and UG Lines."** The remaining calculations make adjustments for the length of the line, the life of the line (default: 35 years) and the loss of life expectancy.

Electrocution Rate per 100,000

The Statistical Abstracts of the United States (1994) state that there were 670 electrocutions in the U.S. in 1990 – a number that has been steadily declining. Using this number results in a rate of 0.3 electrocutions per 100,000 population in the U.S.

Number of Electrocutions in CA

Multiplying the electrocution rate by 300 to reflect the 30 million population of California results in 90 electrocutions. We need to subtract from this number the cases of worker electrocution (see the worker electrocution model) which amounted to 25 cases per year. Thus the net estimate of public electrocutions for California is 65.

Percent of Electrocutions due to OH Lines

Data by the California Division of Labor Statistics Research (1998) suggest that about 46% of worker electrocutions are due to overhead line contact. This is probably an upper bound for public electrocutions, which are more likely to occur in or around the house. The model has three possible values for the percent of electrocutions due to OH lines: 20% (low), 30% (medium), and 50% (high). At 30%, this would result in an estimated 0.30*65=19.5 electrocutions.

Worker Fatalities due to Contact with Electric Current (1992-1996)

	OH Lines	Appliances	Other	Percent OH
1992	13	7	5	52%
1993	10	8	8	38%
1994	10	4	10	42%
1995	11	2	10	47%
1996	14	3	10	52%
Av.	**11.6**	**4.8**	**8.6**	**46%**

California Division of Labor Statistics and Research. Census of Fatal Occupational Injuries. San Francisco, Web Site: www.dir.ca.gov/DIR/S&R/table1.html, 1998.

Percent of electrocutions due to UG Lines

There is no data that directly identifies electrocutions due to contact with underground cables. A 1995 CPUC report states that there were 2 electrocutions in California in one year due to this type of contact. It is not known whether these electrocutions were public or worker cases. Assuming that one case per year is a public electrocution, this would be 5% of the estimated public OH electrocutions. Using this 5% as a benchmark, the model uses 1% (low), 1.5% (medium) and 2.5% (high) as scenario settings for the percentage of public electrocutions due to underground lines.

Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

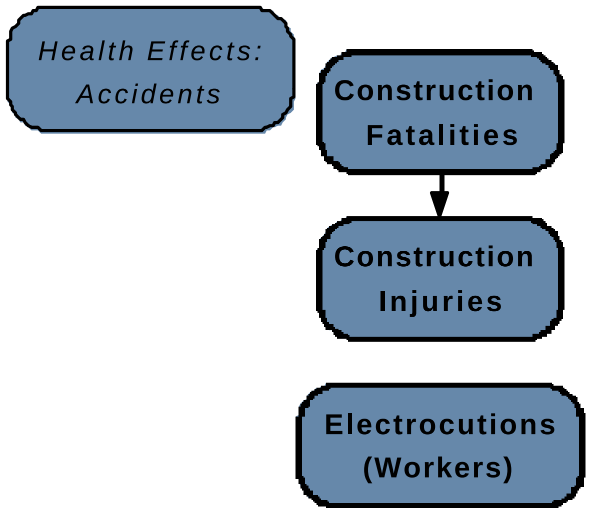
Total Miles of UG Lines

This single value specifies the total miles of underground lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 80,000 miles of underground lines. According to the California Energy Commission (1998), the IOUs own approximately 82% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 100,000 miles of underground lines.

Utilities Report to the CPUC, 1997.

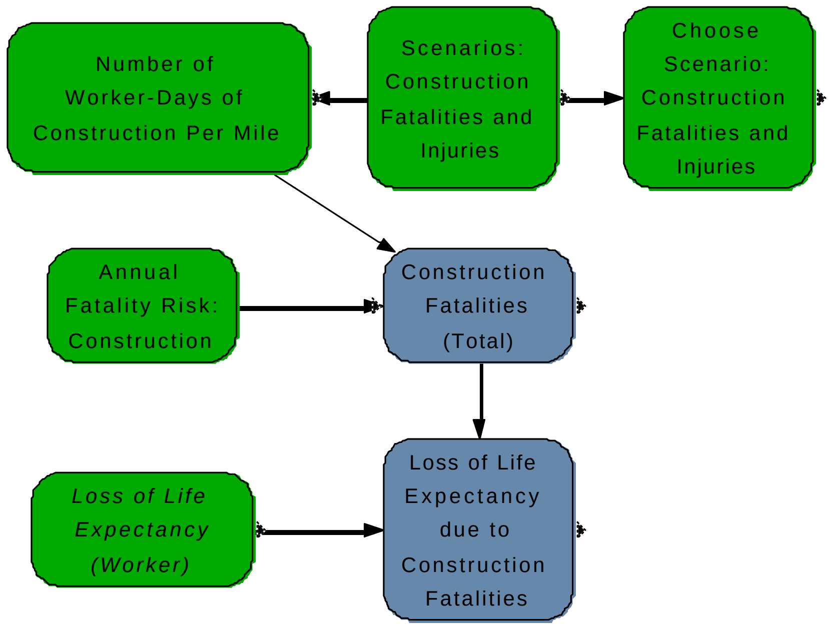
California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Model – Criteria – Accidents: Workers



Accidents: Workers
This model estimates the worker fatalities and injuries due to construction, for example, when undergrounding an existing transmission or distribution line. In addition, the model estimates the worker fatality risk due to electrocutions.

Model – Criteria – Accidents: Worker – Construction Fatalities



Construction Fatalities (Injuries)

The "**Construction Fatalities (Injuries) (Total)"** depend on the "**Number of Worker-Days of Construction Per Mile"** and the **"Annual Fatality Risk: Construction."** The **"Number of Worker-Days of Construction Per Mile"** depend on the alternative chosen. In general, undergrounding has the largest number of construction days, but other alternatives like split phasing, raising the pole height, etc, will also involve construction. For fatalities, the **"Loss of Life Expectancy due to Construction Fatalities"** is then calculated from the total construction fatalities.

Annual Fatality (Injury) Risk: Construction

According to the Bureau of Labor Statistics (1994), the annual fatality risk from construction is 0.00033. The user can update this number as more recent information or information that is specific to utility construction becomes available. The annual risk of a serious injury is 0.067 (Bureau of Labor Statistics, 1993).

Bureau of Labor Statistics. Fatal Workplace Injuries in 19934: Data and Analysis. Washington, DC: U.S. Department of Labor, 1994.

Bureau of Labor Statistics. Occupational injuries and illnesses in the United States by Industry. Washington, DC: U.S. Department of Labor, 1993.

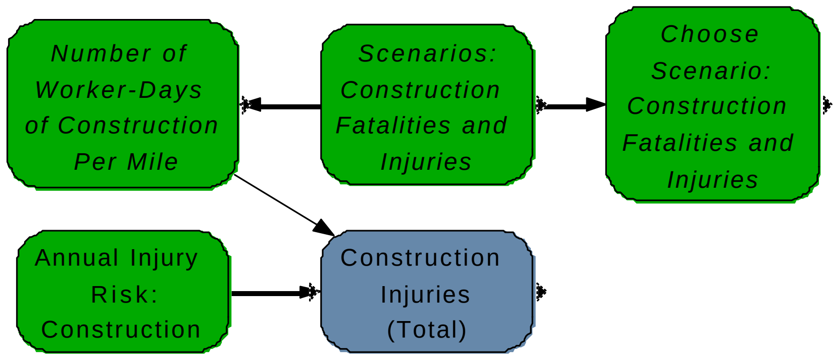
Number of Worker-Days of Construction Per Mile

This table lets the user edit the number of worker-days of construction per mile for three scenarios (low, medium, high) and each alternative that involves construction. The estimates in the table were obtained from William Gray, a consultant to Decision Insights, Inc. The default is the medium scenario.

Worker-Days of Construction per mile:

Overhead Transmission – Pole: 30 (low), 35 (medium), 40 (high)
Overhead Transmission – Towers: 200 (low), 250 (medium), 300 (high)
Overhead Distribution – Pole: 15 (low), 20 (medium), 30 (high)
Underground Transmission: 1800 (low), 3,000 (medium), 5000 (high)
Underground Distribution: 35 (low), 40 (medium), 50 (high)

Model – Criteria – Accidents: Workers – Construction Injuries



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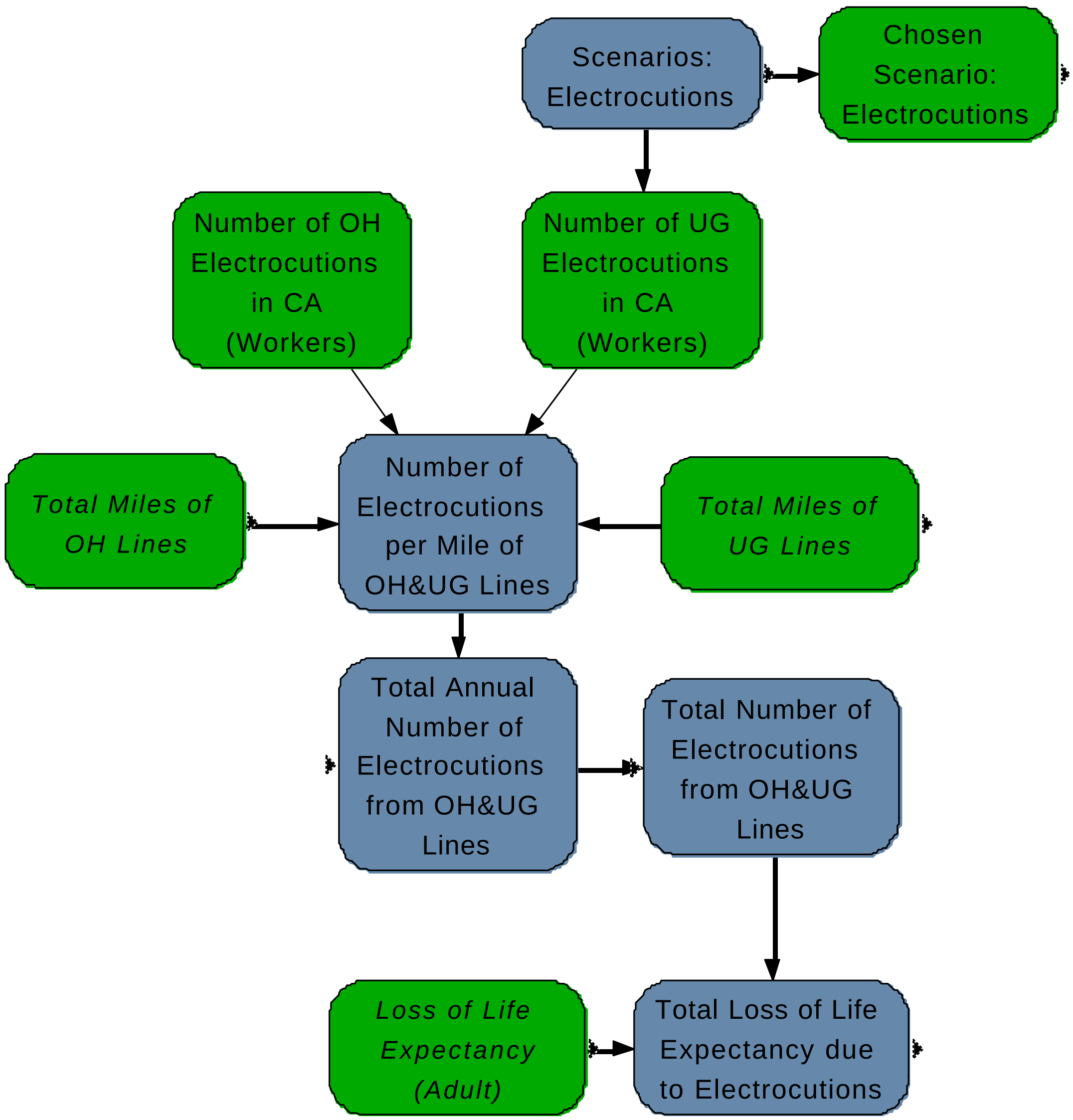
Model – Criteria – Accidents: Workers - Electrocutions



Electrocution (Workers)

This model builds on an estimate of the annual "**Number of OH Electrocutions in California (Workers)**" due to contact with overhead lines and the "**Number of UG Electrocutions in California (Workers)**" due to contact with underground lines. It converts the annual number of electrocutions into a "**Number of Electrocutions per Mile of OH and UG Lines**" by using the respective **"Total Miles of OH Lines"** and the **"Total Miles of UGLines"** in California, then calculates the **"Total Annual Number of Electrocutions from OH and UG Lines"** by multiplying the length of the line with the per-mile risk**.** The remaining calculations extrapolate this result to the lifetime of the line (default: 35 years) and reductions in life expectancy.

Number of OH Electrocutions in CA (Workers)

This model includes electrocution risks both from line workers and other workers that may come in contact with power lines. The best statistics for this purpose come from the California Division of Labor Statistics Research (1998):

Worker Fatalities due to Contact with Electric Current (1992-1996)

	OH Lines	Appliances	Other
1992	13	7	5
1993	10	8	8
1994	10	4	10
1995	11	2	10
1997	14	3	10
Av.	**11.6**	**4.8**	**8.6**

California Division of Labor Statistics and Research. Census of Fatal Occupational Injuries. San Francisco, Web Site: www.dir.ca.gov/DIR/S&R/table1.html, 1998.

Number of UG Electrocutions in CA (Workers)

None of the labor risk statistics bracket out underground cables as a source of worker electrocutions. The "Other" category of the California Division of Labor Statistics and Research includes contact with wiring, transformers and other electrical components. One source (CPUC, 1985) list 2 electrocutions due to contact with underground lines in one year, but it is unclear whether these were workers or members of the public. The model uses three values -- 0 (low), 1 (medium) and 2 (high) -- for the estimated number of electrocutions due to underground cables in California.

Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

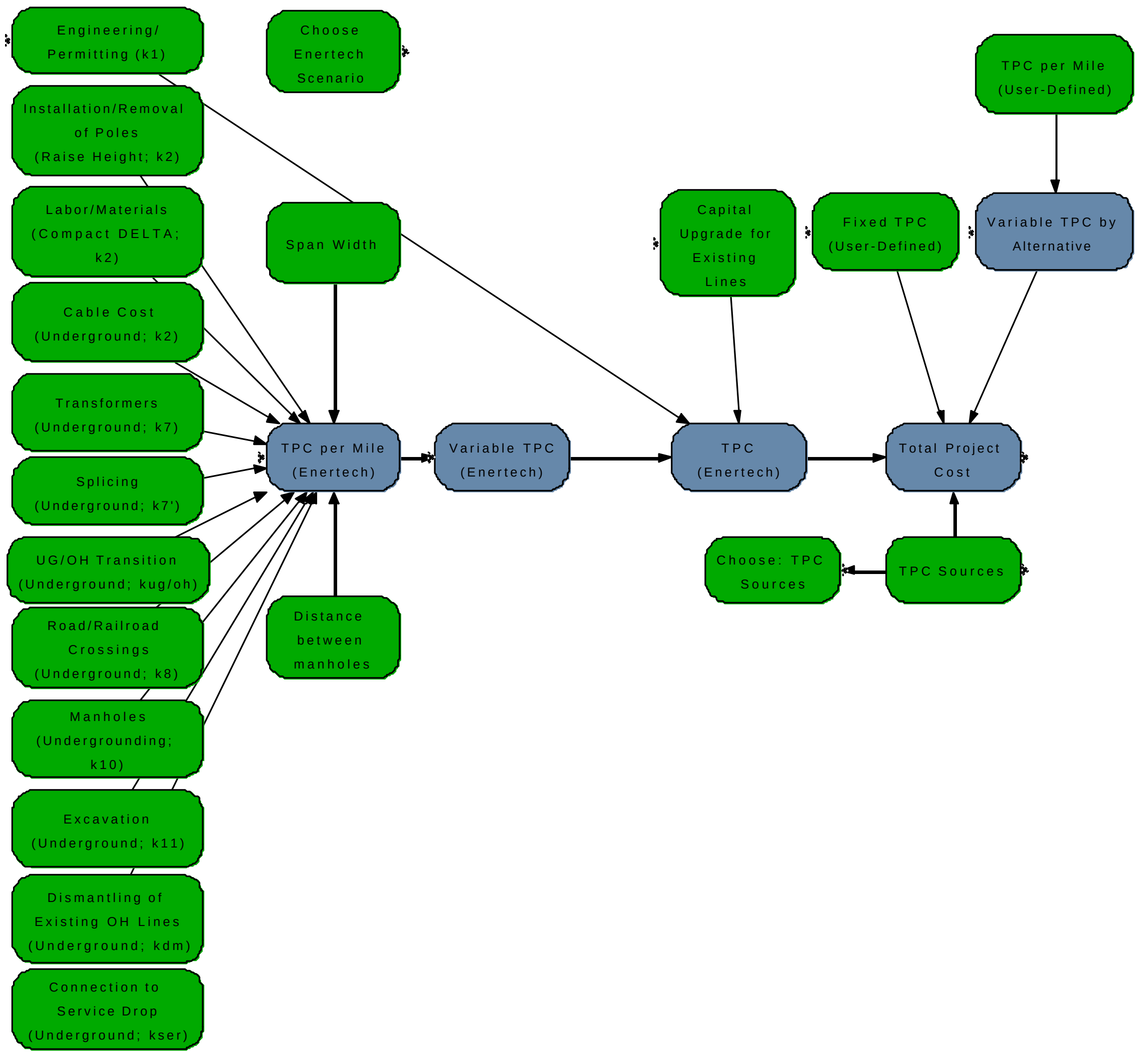
Total Miles of UG Lines

This single value specifies the total miles of undergrund lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 80,000 miles of underground lines. According to the California Energy Commission (1998), the IOUs own approximately 82% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 100,000 miles of underground lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Model - Criteria – TPC



Total Project Cost – TPC

This model estimates the **"Total Project Cost,"** i.e., the design, engineering, and construction costs, of the alternatives considered based on data by Enertech Consultants (1998a, 1998b). The use of these documents to estimate costs for the Analytica model is described in Decision Insights, Inc., 1999, Appendix C (Cost). To understand the component estimates (e.g., engineering/permitting, pole installation/removal, cable cost) users of this model are referred to the two Enertech sources. Model users can also specify the total project costs directly using **"Fixed TPC (User-Defined)"** and **"TPC per Mile (User Defined)."** To specify the source for the TPC calculations, the user can choose between "Enertech" and "User-Defined" in the **"Choose: TPC Sources"** node. If Enertech's data are used, the user can also specify whether to use a low, medium, or high value from the **"Choose Enertech Scenario"** node.

The number and nature of individual TPC components depend on the particular scenario, in particular what mitigation options are considered. For example, the TPC components for undergrounding are very different from those of split-phasing. Thus, users would have to make substantial changes to this module if a new scenario were to be constructed and if they would like to explicitly model the individual cost components (by using the Enertech reports, for example). On the other hand, the user can always supply fixed and variable (per mile) cost components and choose to run the model with the user supplied values. This is achieved by choosing "User-Defined" from the **"TPC Sources"** node.

For some alternatives the model assumes the need for capital upgrades to assure that the line can be used for the projected life (default: 35 years). For example, if an existing overhead line is 30 years old, the model allows the user to specify the upgrade cost to assure that this line will have an additional lifetime of 35 years. For new lines, we assume a 35 year life without capital upgrades.

Enertech Consultants. Electric and Magnetic Field Exposure Assessment of Powerline and Non-Powerline Sources for Public School Environments. DRAFT, October 1998a.

Enertech Consultants, Magnetic Field Mitigation Cost Estimates, DRAFT, June 1998b.

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Engineering/Permitting (k1)

This cost component reflects the cost of engineering (including construction management), permits, etc. expressed as a percentage of the total project cost. The default value is 15% for raising the poled height and conversion to a compact delta configuration, and 25% for undergrounding (see Decision Insights, Inc., 1999). This TPC component applies to all mitigation options.

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Installation/Removal of Poles (Raise Height, k2)

For the "Raise Pole Height" mitigation option, this TPC component reflects the cost of taller poles, including the installation of new and the removal of old poles. The default value is $4,175 (see Decision Insights, Inc, 1999, Appendix C). In order to calculate the per-mile cost, the model assumes a default value of 300 feet for the span width. This value can be changed in the **"Span Width"** node.

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999

Labor/Materials (Compact DELTA, k2)

For the "Compact DELTA" mitigation option, this component reflects the cost of labor and materials need to move the conductors and insulators. The default value is $1,750 per pole (see Decision Insights, Inc, 1999, Appendix C).

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, April, 1999.

Cable Cost (Underground, k2)

For the "Underground" mitigation option, this component accounts for the cable cost. The default value is $4.77 per foot (see Decision Insights, Inc, 1999, Appendix C). Note: This component has to be applied to each conductor.

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, April, 1999.

Transformers (Underground, k7)

For the "Underground" mitigation option, this component reflects the cost of primary transformers. The default value is $9,410 per transformer. The distance between transformers is assumed to be 200 feet. (see Decision Insights, Inc, 1999, Appendix C).

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Splicing (Underground, k7')

For the "Underground" mitigation option, this component reflects the cost of splicing together cable sections, which are limited in length to at most about 1/2 mile. The default value is $8.64 per foot (see Decision Insights, Inc, 1999, Appendix C).

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

UG/OH Transition (Underground, kug/oh)

For the "Underground" mitigation option, this component reflects the cost of each UG/OH transition. This includes a 600A/200A splice, a 3-phase pot head, and a fuse. The default value is $4,500 (see Decision Insights, Inc, 1999, Appendix C).

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Road/Railroad Crossings (Underground, k8)

For the "Underground" mitigation option, this component reflects the cost of road and railroad crossings with a default value of $5.68 per foot (see Decision Insights, Inc, 1999, Appendix C).

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Manholes (Underground, k10)

For the "Underground" mitigation option, this component reflects the cost of manholes. The default value is $2,100 per manholes. The average distance between manholes is assumed to be 600 feet.

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Excavation (Underground, k11)

For the "Underground" mitigation option, this component reflects the excavation cost, which will vary depending on the physical characteristics of the scenario modeled (e.g., soil conditions). The default value is $22.32/foot (see Decision Insights, Inc, 1999, Appendix C).

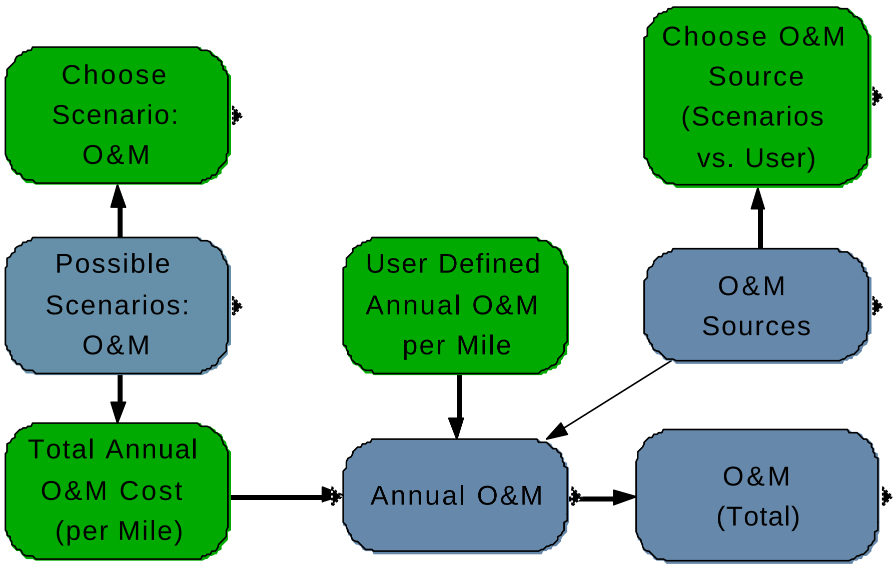
Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Dismantling of Existing OH Lines (Underground, kdm)

For the "Underground" mitigation option, this component reflects the cost of dismantling existing overhead lines with a default value of $8.28 per foot (see Decision Insights, Inc, 1999, Appendix C).

Decision Insights, Inc. Power Grid and Land Use Policy Analysis, Appendix C (Cost). DRAFT, 1999.

Model – Criteria – O&M



O&M

The operation and maintenance (O&M) cost can be either specified by selecting one of three scenarios or directly defined by the user. The costs are specified on an annual per-mile basis.

Total Annual O&M Cost (per Mile)

The O&M costs tend to be somewhat lower for transmission lines than for distribution lines, but both costs are within the range of the scenarios. Some lower costs have been reported by individual utilities (e.g., SCE reports about $500 per mile for OH and UG distribution lines). Also, some higher costs have been reported (e.g., SDG&E reports about $5,000 per mile for distribution lines, due to a large charge for tree trimming in one year). However, O&M ranges shown in the table below cover most of the data reported by the California IOUs and by Gorham and Partners (1995).

Annual O&M costs per mile

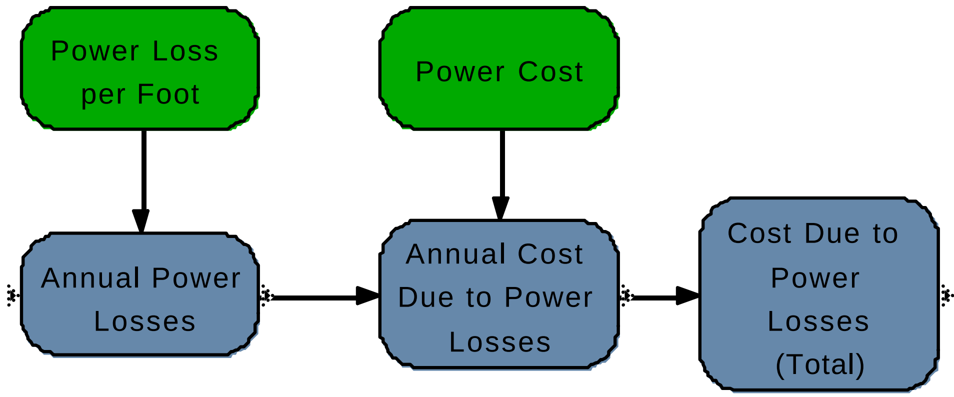
	OH	UG
High	$2,500	$2,000
Medium	$1,800	$1,500
Low	$1,000	$1,000

Sources:

Investor Owned Utilities. Report to the CPUC, 1998.

Gorham and Partners. An analysis of the economics of undergrounding in the European electric utility sector. London: Gorham and Partners, 1995.

Model - Criteria - Conductor Losses



Conductor Losses

This model calculates the cost due to conductor losses. The main input factors are the **"Power Loss per Foot"** and the **"Power Cost."** Both variables have to be specified by the user. Details are given below. The model then calculates the **"Annual Power Losses"** and the **"Annual Cost Due to Power Losses."** Finally, the annual cost are multiplied by the projected life (default value: 35 years) to come up with the **"Cost Due to Power Losses (Total)."** Some aspects of the power loss calculations (in particular the specification of **"Power Loss per Foot"**) are quite complex and the user is referred to the two Enertech documents cited below that provide more detail about various assumptions (e.g., about the materials used in different conductors).

Enertech Consultants. Electric and Magnetic Field Exposure Assessment of Powerline and Non-Powerline Sources for Public School Environments. DRAFT, October 1998a.

Enertech Consultants, Magnetic Field Mitigation Cost Estimates, DRAFT, June 1998b.

Power Loss per Foot

The **"Power Loss per Foot"** (in W/ft) is calculated from the peak current I (in Amperes), the conductor resistance R (in Ohms per mile), the number of conductors NC, and a loss factor LF. The formula is as follows:

Power Loss per Foot = I^2 x R x NC x LF.

For underground lines, dielectric losses are an additional factor that contributes to power losses.

The following example illustrates how the "Power Loss per Foot" is calculated for different peak currents and for overhead and underground lines in a distribution line scenario.

Illustration:
Assuming a peak current of 600 Amperes, three conductors and a loss factor of 0.33, the "Power Loss per Foot" would be:
Power Loss per Foot = $(600)^2$ x 0.00002519 x 3 x 0.33 = 8.98
The resistance value of 0.00002519 is based on a resistance of 0.133 Ohm/mile (see Enertech reports).
For XLPE, the "Power Loss per Foot" would be calculated as follows:
Power Loss per Foot = $(600)^2$ x 3 x 0.00002879 x 0.33 + 0.91 = 11.17
The resistance is "scaled" from the resistance value used in the overhead case, using the relative power losses per foot provided by Enertech. In this case, the scaling factor is (31.09)/27.2. The additional 0.91 W/ft accounts for dielectric losses (again, this value is taken from the Enertech report).

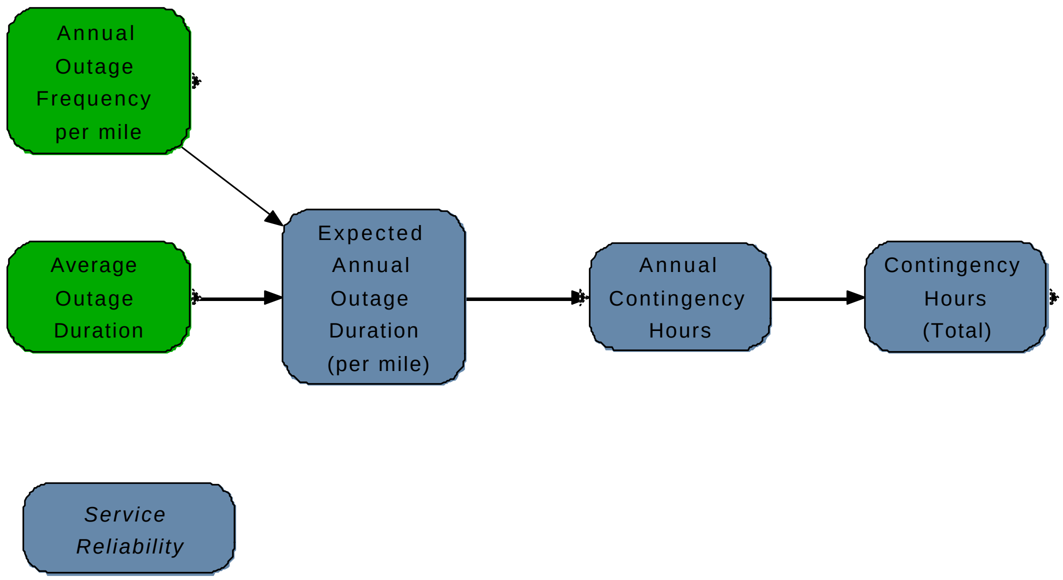
Enertech Consultants. Electric and Magnetic Field Exposure Assessment of Powerline and Non-Powerline Sources for Public School Environments. DRAFT, October 1998a.

Enertech Consultants, Magnetic Field Mitigation Cost Estimates, DRAFT, June 1998b.

Power Cost

The **"Power Cost"** reflects the marginal cost to a utility to provide one kWh of power. The default value is $0.03.

Model – Criteria – Contingencies



Contingencies

This model calculates the contingency hours due to transmission line outages. A contingency is a vulnerable state of the transmission line system due to an outage of a line in this system. Even though there may not be any customer disruptions, a contingency is undesirable, because another outage could lead to severe disruptions. The model calculates the product of an estimated **"Annual Outage Frequency per Mile**" of transmission line with the **"Average Outage Duration"** to obtain the **"Expected Annual Outage Duration (per mile)** and the **"Annual Contingency Hours."**

Annual Outage Frequency per mile

This table lets the user edit the annual outage frequency for overhead and underground lines for the voltage class and configuration considered in the scenario. The default values come from the Canadian Electricity Association (1991-1995) data as reported in Billinton et al. (1995) and checked against data reported by EPRI (1997). The reported frequencies are for line or cable outages only (not included are outages originating with a failure of terminals, transformer banks, etc.). Only sustained outages (> 1min) are considered.

Following are the frequency data calculated from the CEA database (CEA, 1995, 1996) and Billinton et al. (1995). All overhead distribution line (OH-DL) data refer to 601-80 kV lines. Underground distribution lines (UG-DL) are from 17-80 kV lines (mostly 17-40 kV, primarily XLPE).

Line Type	Frequency/Mile/Year
UG-DL	0.0489
UG-115	0.0058
UG 230	0.0033
OH-DL	0.0464
OH-115	0.0040
OH-230	0.0016

Canadian Electricity Association. Forced Outage Performance of Distribution Equipment (1991-1992). Montreal, CA: CEA, 1995.

Canadian Electricity Association. Forced Outage Performance of Transmission Equipment (1991-1995). Montreal: CEA, 1996.

Billinton, R. and Wenyuan, L. Reliability Assessment of Electric Power Systems Using Monte Carlo Methods. New York: Plenum Press, 1994.

Electric Power Research Institute. Application of EPRI's Transmission Reliability Evaluation for Large-Scale Systems (TRELSS) Program to Bonneville Power Administration. TR-108815. Palo Alto: EPRI, 1997.

Billinton, R. et al. Transmission Equipment Reliability Using the Canadian Electricity Association Information System. The Reliability of Transmission and Distribution Equipment, March 29-31 Conference Publication No. 406, IEE, 1995.

Average Outage Duration

This table lets the user edit outage durations by line type and OH vs. UG classification. The default values come from the Canadian Electricity Association (1991-1995) data as reported in Billinton et al. (1995) and checked against data reported by EPRI (1997). The reported frequencies are for line or cable outages only (not included are outages originating with a failure of terminals, transformer banks, etc.). Only sustained outages (> 1min) are considered.

Following are the outage durations calculated from the CEA database (CEA, 1995, 1996) and Billinton et al. (1995). All overhead distribution line (OH-DL) data refer to 12-80 kV lines. Underground distribution lines (UG-DL) are from 17-80 kV lines (mostly 17-40 kV, primarily XLPE).

Line Type	Outage Duration/Occurrence (h)
UG-DL	3.6
UG-115	79.1
UG 230	111.7
OH-DL	2.5
OH-115	6.9
OH-230	15.0

Canadian Electricity Association. Forced Outage Performance of Distribution Equipment (1991-1992). Montreal, CA: CEA, 1995.

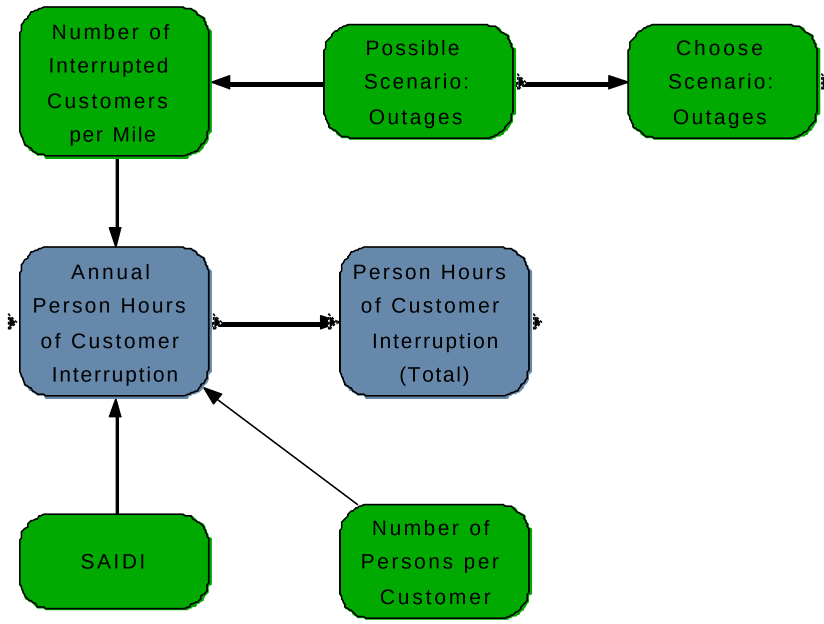
Canadian Electricity Association. Forced Outage Performance of Transmission Equipment (1991-1995). Montreal: CEA, 1996.

Billinton, R. and Wenyuan, L. Reliability Assessment of Electric Power Systems Using Monte Carlo Methods. New York: Plenum Press, 1994.

Electric Power Research Institute. Application of EPRI's Transmission Reliability Evaluation for Large-Scale Systems (TRELSS) Program to Bonneville Power Administration. TR-108815. Palo Alto: EPRI, 1997.

Billinton, R. et al. Transmission Equipment Reliability Using the Canadian Electrical Association Information System. The Reliability of Transmission and Distribution Equipment, March 29-31 Conference Publication No. 406, IEE, 1995.

Model – Criteria – Customer Interruptions

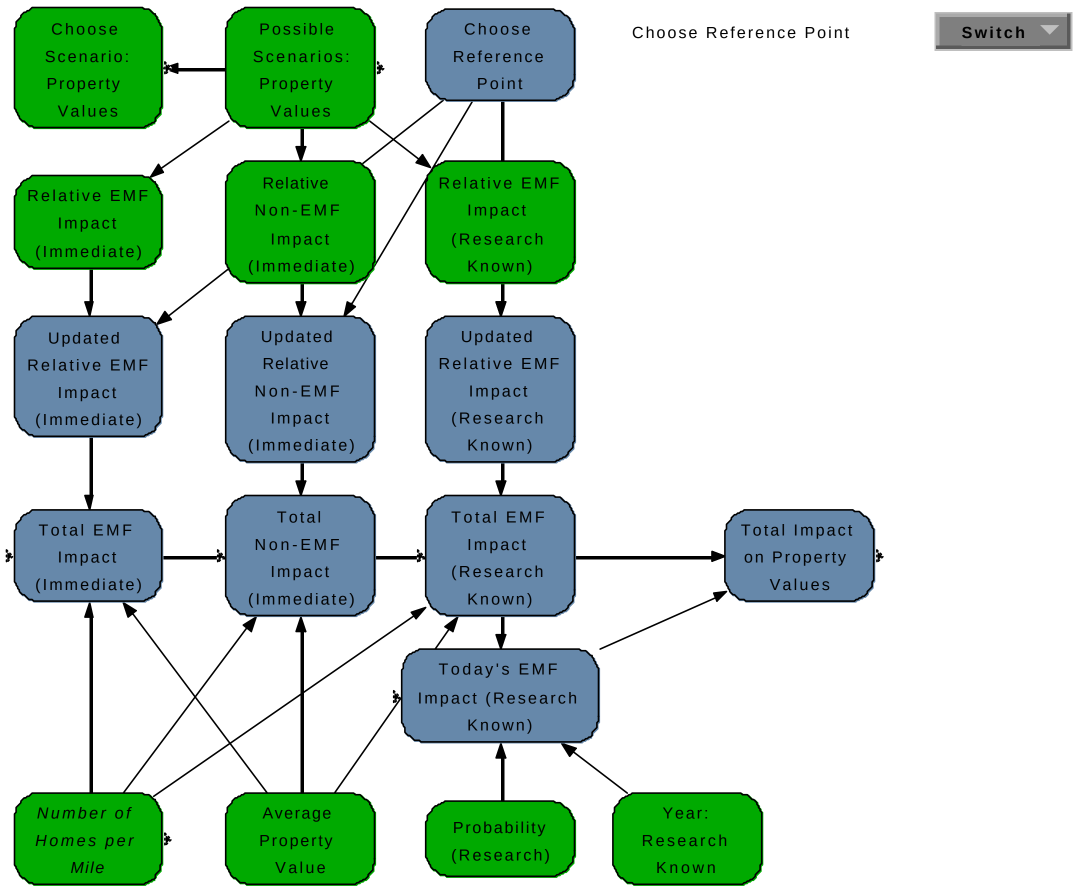


Customer Interruptions

This model calculates the total **"Person-Hours of Customer Interruptions (Total)"** based on the **"Number of Interrupted Customers per Mile,"** the **"Number of Persons per Customer,"** and **"SAIDI"** values.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Model – Criteria – Property Values



Property Values

Because so little is known about the property values impact of electromagnetic fields exposure, the property values model is highly scenario driven. It divides property values impacts into those due to an EMF effect (left side of the diagram) and a non-EMF effect, e.g. due to aesthetics, noise, and radio interference (middle of the diagram). As a benchmark, the high-quality property values studies suggest that there is a property value reduction of around 5-6% for properties near transmission lines, mostly due to the visual impacts (see Hamilton and Schwann, 1995; Gregory and von Winterfeldt, 1996).

Based on a user-selected choice of a "**Possible Scenario: Property Values"** (top of the diagram) the model determines the "**Relative EMF Impact (Immediate)"** and the **"Relative Non-EMF Impact (Immediate)"** in percent depreciation or appreciation. The model also defines the "**Relative EMF Impact (Research Known),"** which is a function of the outcome of future EMF research (i.e, positive, conflicting, or negative). If research is negative, the properties that are now undervalued due to an EMF effect would appreciate, if research remains conflicting, they would stay the same, and if research is positive, they may be further reduced.

The sum of the EMF and non-EMF impacts are determined separately for each research scenario. With user specified probabilities of the possible research outcomes ("**Probability(Research)"**) an expected percent depreciation or appreciation is calculated for a defined year when research becomes known (**"Year: Research Known"**). With these calculations, the "**Total Non-EMF Impact"** and the **"Total EMF Impact"** can be calculated in percent.

Other variables that determine the total property value depreciation or appreciation are the **"Number of Homes per Mile"** of transmission or distribution line and the "**Average Property Value"** of a home. Given the total non-EMF impact and the total EMF impact, the number of homes per mile, the number of miles, and the average property value, the model then calculates the "**Total Impact on Property Values**."

The **"Choose Reference Point"** option allows the user to choose whether the model uses the relative impacts on property values "as defined" or "switched." For example, if relative impacts are defined as gains for undergrounding a line segment in the **"Relative EMF Impact (Immediate)," "Relative Non-EMF Impact (Immediate),"** and **"Relative EMF Impact (Research Known)"** variables then choosing "Switched" from the **"Choose Reference Point"** option will reverse the calculations by penalizing line segments that are not underground with the corresponding cost.

The illustrative use of the property values model is for distribution lines. In the transmission line retrofitting model, higher depreciation or appreciation values are used throughout. All retrofitting models use appreciation, when a mitigation alternative eliminates the negative impacts on property values or when research is negative, depreciation in case of positive research. Also note that mitigation measures that are not likely to affect the perception of the EMF exposure (such as delta configuration or raising the pole height) are not credited with appreciation. New Transmission line models use depreciation for construction that creates new impacts on property values.

DISCLAIMER: All values are based on very limited data. Most high-quality property values show some depreciation of properties near transmission lines, though much less is known about distribution lines. Most of the depreciation appears to be due to visual impacts. It is impossible to determine the effect of EMF risks or fears that they may have produced on property values. As a result, the users should revisit and re-assess all appreciation and depreciation percentages in these tables to reflect their own judgments.

Hamilton, S. and Schwann, G. Do high voltage transmission lines affect property value? Land Economics, 71, 1995, 436-44.

Gregory, R. and von Winterfeldt, D. The effects of electromagnetic fields from transmission lines on public fears and property values. Journal of Environmental Management, 48, 1996, 201-214.

Relative EMF Impact (Immediate)

The low, medium, and high scenarios for distribution lines are

No Change: 0% (low), 0% (medium), 0% (high)
Compact Delta: 0% (low), 0% (medium), 0% (high)
Raise Height: 0% (low), 0% (medium), 0%(high)
Underground: 0% (low), -2.5% (medium), -5% (high)

Relative Non-EMF Impact (Immediate)

The low, medium, and high scenarios for distribution lines are

No Change: 0% (low), 0% (medium), 0% (high)
Compact Delta: 0% (low), 0% (medium), 0% (high)
Raise Height: 0% (low), 0% (medium), 0%(high)
Underground: 0% (low), -2.5% (medium), -5% (high)

Relative EMF Impact (Research Known)

Positive Research – low, medium and high values for distribution lines

No Change: 0% (low), 5% (medium), 10% (high)
Compact Delta: 0% (low), 5% (medium), 10% (high)
Raise Height: 0% (low), 5% (medium), 10%(high)
Underground: 0% (low), 0% (medium), 0% (high)

Conflicting Research– low, medium and high values for distribution lines

No Change: 0% (low), 0% (medium), 0% (high)
Compact Delta: 0% (low), 0% (medium), 0% (high)
Raise Height: 0% (low), 0% (medium), 0%(high)
Underground: 0% (low), 0% (medium), 0% (high)

Negative Research– low, medium and high values for distribution lines

No Change: 0% (low), -2.5% (medium), -5% (high)
Compact Delta: 0% (low), -2.5% (medium), -5% (high)
Raise Height: 0% (low), -2.5% (medium), -5%(high)
Underground: 0% (low), 0% (medium), 0% (high)

Number of Homes per Mile

The model counts only the homes directly located near the transmission or distribution lines. The default value is 50 homes on each side of the line for a typical residential segment. The user can control this input for each segment in the **"Design and Assumptions"** menu.

Average Property Value

This menu lets the user access a table that specifies the average property values by segments of the line. The geographic information systems study commissioned by DII (Impact Assessment, 1998), showed average property values near sub-transmission and transmission lines to range from about $125,000 to $185,000 in 1990. Property values probably decreased during the 90s real estate recession, but may be somewhat higher now. Typical values used in the model are $150,000 and $200,000 depending on segments.

Impact Assessment. GIS analysis of State-wide transmission lines. La Jolla: Impact Assessment, Inc., 1999.

Probability (Research)

This table defines the probabilities for the three possible research outcomes: Positive, Conflicting, and Negative. The default values are p(Positive)=.05, p(Conflicting)=.725, p(Negative)=.225.

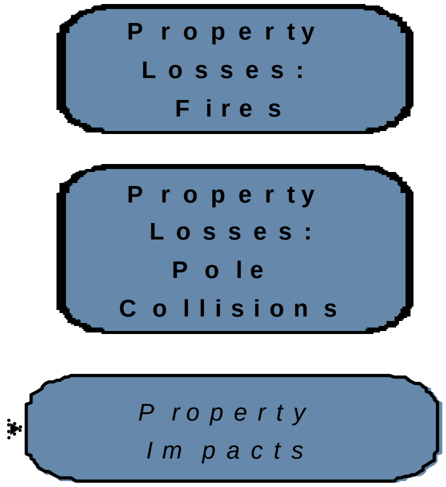
Year: Research Known

This menu specifies the year when the research outcome will be known. The default value is 14 years. The user can change this to any number from 0 (now) to 35 (the useful lifetime of the transmission or distribution line).

Choose Reference Point

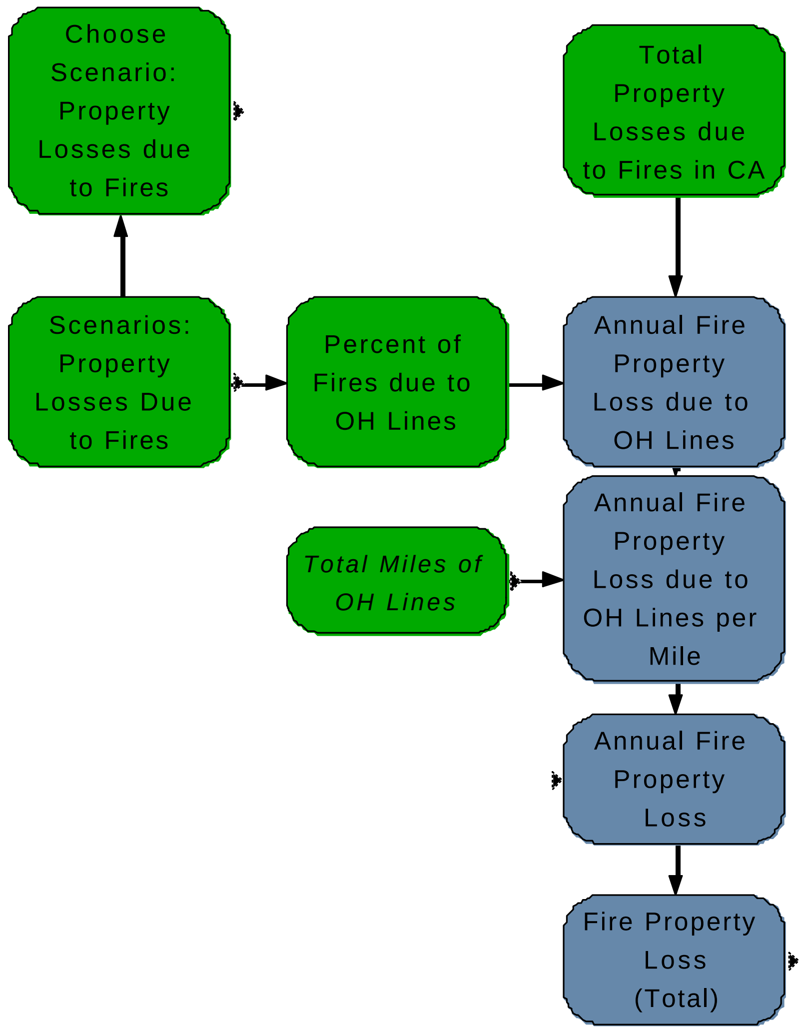
This option allows the user to choose whether the model uses the relative impacts on property values "as defined" or "switched." For example, if relative impacts are defined as gains for undergrounding a line segment in the **"Relative EMF Impact (Immediate)," "Relative Non-EMF Impact (Immediate),"** and **"Relative EMF Impact (Research Known)"** variables then choosing "Switched" from the **"Choose Reference Point"** option will reverse the calculations by penalizing line segments that are not underground with the corresponding cost.

Model – Criteria – Property Losses



Property Losses
This model calculates the property losses due to fires and pole collisions.

Model – Criteria - Property Losses: Fires



Property Losses: Fires

The model calculates the **"Annual Fire Property Loss"** due to transmission and distribution lines as a function of the annual "**Total Property Losses due to Fires"** (about $800 million/year) in California and the "**Percent of Property Loss due to OH Lines."** This percentage is uncertain (an upper bound is about 11% for all electrical distribution sources). To accommodate this uncertainty, the model lets the user input reasonable high and low scenarios for the **"Percent of Property Loss due to OH Lines."** With the **"Annual Fire Property Loss due to OH Lines"** for the whole state, and the statewide length of overhead lines, we can then calculate the **"Annual Fire Property due to OH Lines per Mile"** of transmission and distribution lines. Applying the length of miles for each segment of the scenario, we can then calculate the "**Annual Fire Property Loss"** summing over segments and, summing over years (with possible discounting) the "**Fire Property Loss (Total)"** can be determined.

Percent of Fires due to OH Lines

According to the National Fire Data Center (1978) about 11% of all fires are due to electrical distribution. This includes overhead and underground transmission and distribution. It is unclear whether this percentage includes wiring in buildings, but the data in the referenced report do not include electrical wiring in buildings as a separate source from "electrical distribution." In any case, the 11% figure is an upper bound for the percentage of fires due to distribution and transmission lines. We further assume that all fires are due to overhead (OH) lines, none to underground (UG) lines and that the percent of fires is identical to the percent of fatalities (injuries).

To reflect the uncertainties in the estimation of this percentage, the user can use three settings:

Low: 1%
Medium: 5%
High: 15%

National Fire Data Center. Fire in the United States. Washington, DC: U.S. Department of Commerce, 1978.

Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

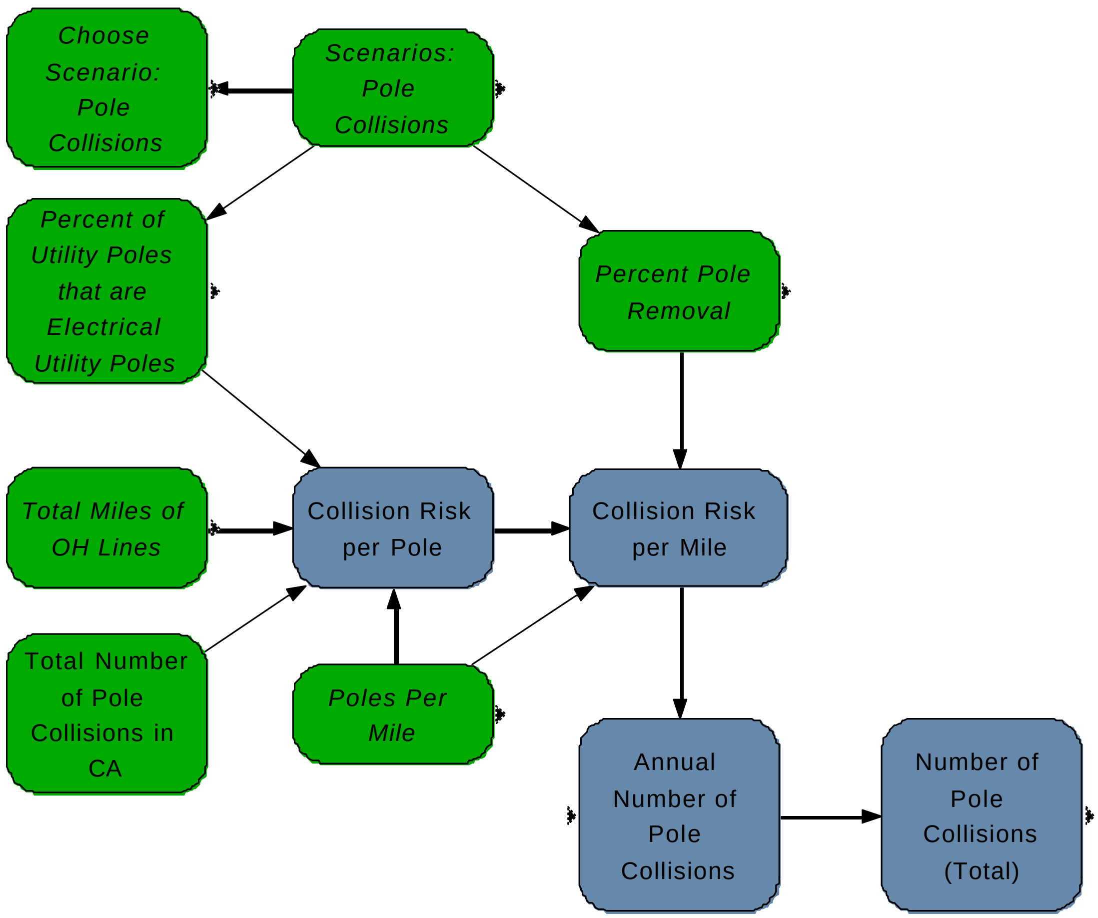
California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Total Property Losses Due to Fires

This expression specifies the total property loss due to fires in one year in California. The default value of $800 million is a 10 year average of actual property losses reported in California by the California Fire Marshal (1988).

California State Fire Marshal. California Fire Incident Reporting System. Sacramento: Office of the State Fire Marshal, 1988.

Model – Criteria – Property Losses – Pole Collisions



Property Losses due to Pole Collisions

This model estimates property losses due to utility pole collisions. The key variable is "**Collision Risk per Pole**." It depends on the "**Total Number of Pole Collisions in California (CA)**," the "**Percent of Utility Poles that are Electrical Utility Poles**," the "**Total Miles of OH Lines**," and the "**Number of Poles per Mile**."

The "**Collision Risk per Mile"** for overhead design is the product of the collision risk per pole times the number of poles per mile. The "**Collision Risk per Mile"** for undergrounding an existing overhead line is the residual risk, once the poles for overhead distribution are removed. If all poles are removed, this residual risk is zero. However, some poles may remain, to support existing structures or non-electrical utilities.

Total Number of Pole Collisions in CA

Between 1994 and 1997 there were, on average, 126 automobile crashes with utility pole collisions in California, with 69 fatalities, 49 injuries, and 8 cases with property damage only (see below).

	1994	1995	1996	1997	Average
Fatal	75	69	63	68	**69**
Injury	53	39	58	44	**49**
No Injury	15	10	5	3	**8**
TOTAL	**143**	**118**	**126**	**115**	**126**

Fatal Accident Reporting System (FARS), 1994, 1995, 1996, 1997. US Department of Transportation, National Highway Safety Administration. FARS Web Site: www-fars.nhtsa.dot.gov, FARS Query System, February, 1999.

Percent of Utility Poles that are Electrical Utility Poles

The U.S. Department of Transportation FARS data distinguishes between light posts, sign posts, and utility posts, but it does not distinguish between electrical and other utility posts (telephone and cable). However, one can assume that most utility posts are electrical utility poles or poles that carry multiple utility lines. The user can choose between three values: Low (80%), Medium (90%), and high (100%).

Total Miles of Overhead Lines

This single value specifies the total miles of overhead transmission and distribution lines in California. According to data provided to the CPUC (Utilities Report to the CPUC, 1997), investor owned utilities (IOUs) operate some 250,000 miles of overhead lines. According to the California Energy Commission (1998), the IOUs own approximately 78% of California's transmission and distribution system (California Energy Commission, 1998). Therefore, California has approximately 320,000 miles of overhead distribution lines. If we add 43,000 miles of overhear transmission lines, California has 363,000 miles of overhead lines. There are also about 100,000 miles of underground lines, most of which are distribution lines.

Utilities Report to the CPUC, 1997.

California Energy Commission, website: www.energy.ca.gov/electricity/system_power.html, 1998

Percent Pole Removal

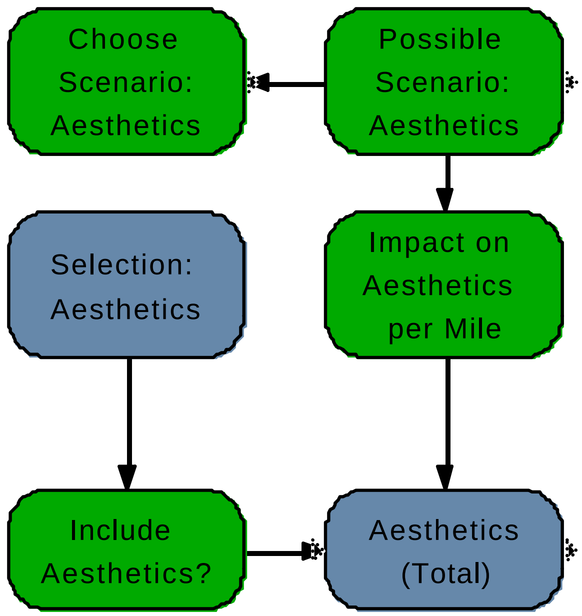
Not all poles will necessarily be removed when an overhead line is undergrounded. For example, poles that carry street lights will either remain to provide light, or they will be replaced by light poles. The model lets the user choose between 50% (low), 75% (medium) and 100% (high) pole removal.

Poles Per Mile

The number of poles can vary as a function of the weight of the line and other factors from 10 per mile to 20 per mile. As a default, the model uses 20 poles per mile.

Source: William Gray, Consultant to Decision Insights, Inc. Personal communication, August, 1998.

Model – Criteria – Aesthetics



Aesthetics

This model provides a preliminary scale for the aesthetic impacts of powerlines based on several physical features. The aesthetics scale “penalizes” lines that have a more obtrusive appearance (e.g., multiple circuits, lattice structure). The scale is to measure the non-property values impact of aesthetics, for example, due to visual impacts on drivers or pedestrians passing through the area.

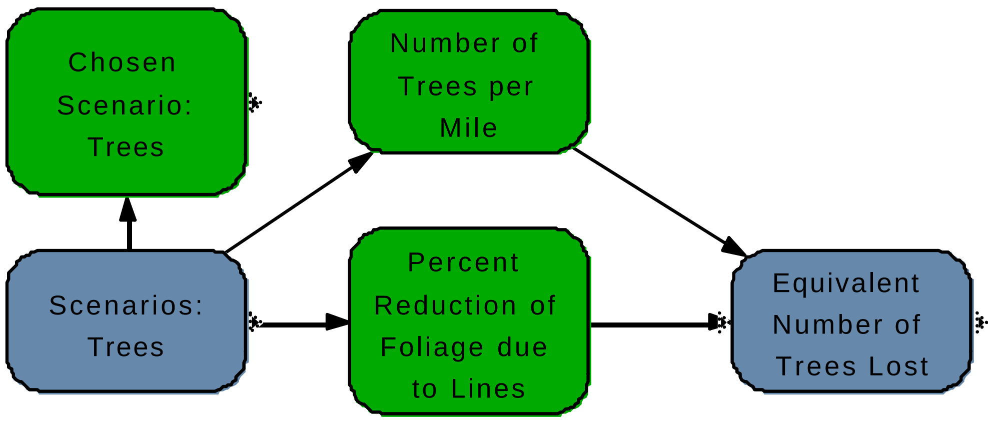
At the core of the aesthetics model is a scoring system that expresses how much “worse” the aesthetic impact of a powerline is than a single circuit overhead (OH) configuration for a primary distribution line (without underbuilt secondaries or other service lines). The scoring system is shown below.

	Single Circuit	Double Circuit or Underbuilt
OH-Lattice	3	4
OH-Tubular	2	3
OH-Pole	1	1.5
UG	0	0

Scores for other designs can be judged by reference to these scores.

The model lets the user choose whether aesthetics is applicable in a scenario (“**Include Aesthetics?”)** and define aesthetics by segments of the line (**“Impact on Aesthetics per Mile”**).

Model – Criteria - Trees



Trees

This model calculates the **"Equivalent Number of Lost Trees"** based on the **"Number of Trees per Mile**," and the **"Percent Reduction of Foliage due to Overhead Lines."**

Number of Trees per Mile

According to one utility's report, there are 400,000 trees that need trimming along 9,140 miles of overhead lines (SDG&E, 1997). This averages out to about 40 trees per mile of OH lines. The user can select from a low (30 trees/mile), medium (40 trees/mile) and high (50 trees per mile) scenario.

San Diego Gas and Electric. Report to the CPUC. 1997.

Percent Reduction of Foliage due to Lines

OH lines limit the growth of trees. However, even without lines, trees would be cut regularly for fire, view, and safety reasons. The user can set the percentage of foliage reduction as a scenario variable from 10% (low) to 20% (medium) to 30% (high). For the new construction scenarios, these reductions are used as a penalty for OH lines. For retrofits, the loss of foliage is considered a sunk cost, and the increase in foliage due to retrofits are considered a benefit.

Model – Criteria – Air Pollution

Air Pollution

This is a fairly complex model that combines the effects of conservation **("Percent Reduction/Increase of Household Electricity Due to Conservation"**), tree shading **("Percent Reduction/Increase of Household Electricity Due to Shading"**), and line losses (**"Relative Line Losses by Alternative")** on the **"Total Increase/Decrease in Required Supply"** of electricity. Current California electricity consumption is about 219 GWh/year (California Energy Commission, 1997). To supply this consumption, approximately 263 GWh/year of electricity need to be produced. The percent increase/decrease in electricity consumption and the relative line losses can be translated into a **"Percent Change in Total Electricity Supply."** This will lead to approximately the same percent reduction in production at the fossil fuel power plants (about 56% of all California power plants use fossil fuel, see California Energy Commission, 1999). The model assumes that the resulting percentage reduction in the use of fossil fuel plants will lead to the same reduction in pollution generated by these plants. This reduction is then applied to an estimated **"Total Annual Cost of Fossil Fuel Pollution in California"** to determine an annual and then a **"Total Equivalent Change of Pollution Cost"**.

California Energy Commission. 1997 California System Power. Web Site: www.energy.ca.gov/electricity/system_power.html., 1999.

Percent Reduction/Increase of Household Electricity Due to Shading

The default values are 0 for overhead lines, and 0 (low), -15% (medium), and –20% (high) for undergrounding. Negative numbers indicate a decrease in household electricity consumption.

Percent Reduction/Increase of Household Electricity Due to Conservation

This reduction/increase depends on the policy alternative. In most models it is assumed to be 0. In special conservation models, it is assumed to vary between 5% and 20%.

Average Household Electricity Use Per Year

Using data provided by the California Energy Commission (1999), we estimate this number to be about 6,000 kWh.

California Energy Commission. 1997 California System Power. Web Site: www.energy.ca.gov/electricity/system_power.html., 1999.

Total Electricity Use per Year in CA

Using data provided by the California Energy Commission (1999), we estimate this number to be about 219 GWh/year.

California Energy Commission. 1997 California System Power. Web Site: www.energy.ca.gov/electricity/system_power.html., 1999.

Total Electricity Supply per Year in CA

Using data provided by the California Energy Commission (1999), we estimate this number to be about 263 GWh/year.

California Energy Commission. 1997 California System Power. Web Site: www.energy.ca.gov/electricity/system_power.html., 1999.

Relative Line Loss by Alternative

This is the line loss calculated in W/ft from the sub-model "Power Loss"

Number of Homes per Mile

The model counts only the homes directly located near the transmission or distribution lines. The default value is 50 homes on each side of the line for a typical residential segment. The user can control this input for each segment in the **"Design and Assumptions"** menu.

Percent of Fossil Fuel Capacity in CA

Using data provided by the California Energy Commission (1999), we estimate this number to be about 56%.

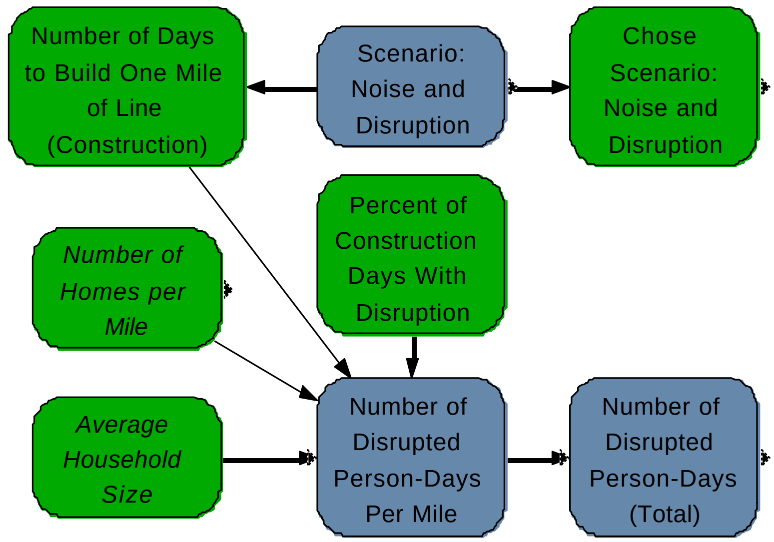
California Energy Commission. 1997 California System Power. Web Site: www.energy.ca.gov/electricity/system_power.html., 1999.

Total Annual Cost of Fossil Fuel Power Plant Pollution in CA

It is hard to estimate the cost of air pollution from fossil fuel power plants. An upper bound might be the cost to eliminate air pollution from fossil fuel power plants. One study in the eighties (Owen et al., 1983) estimated this cost as $10 billion in capital cost and $ 2 billion in annual cost for the nation. Taking ten percent of these estimates to account for California and annualizing the capital cost, the model uses three scenario values of $500 million (low), $750 million (medium), and $1 billion (high).

Owen, M.L., Jarvis, J.B., and Behrens, G.P. Boiler radionuclide emissions control: The feasibility and cost of controlling coal-fired boiler particulate emissions. Technical Report, Radian Corporation, Austin, texas, 1983.

Model – Criteria – Noise and Disruption



Noise and Disruption

The noise and disruption model calculates the "**Number of Disrupted Person-Days (Total)"** due to construction. A key input is the **"Number of Days to Build One Mile of Line (Construction)."** The low, medium, and high estimates were obtained from William Gray, a consultant to Decision Insights, Inc.

Other inputs are the "**Number of Homes per Mile"** and the **"Average Household Size**." With these inputs one can calculate the **"Number of Disrupted Person-Days per Mile"** and, by multiplying this with the number of miles of construction, the "**Number of Disrupted Person-Days (Total)."**

Number of Days to Build One Mile of Line (Construction)

The following estimates were provided by William Gray, consultant to Decision Insights, Inc.:

Overhead transmission – pole: 2 (low), 3 (medium), 4 (high)
Overhead transmission – tower: 5 (low), 6 (medium), 7 (high)
Overhead distribution – pole: 3 (low), 4 (medium), 5 (high)
Underground transmission: 30 (low), 70 (medium), 100 (high)
Underground distribution: 3 (low), 4 (medium), 5 (high)

William Gray, personal communication, 1998, 1999.

Number of Homes per Mile

This is a user determined input (see **“Design and Assumptions”**). In many models, we use a row of single family houses at both sides of the line, with a 50 foot frontage. Allowing for streets, open space, and occasionally wider frontages, we use 50 homes per mile on each side of the line, or 100 homes that would be affected by construction activities.

Average Household Size

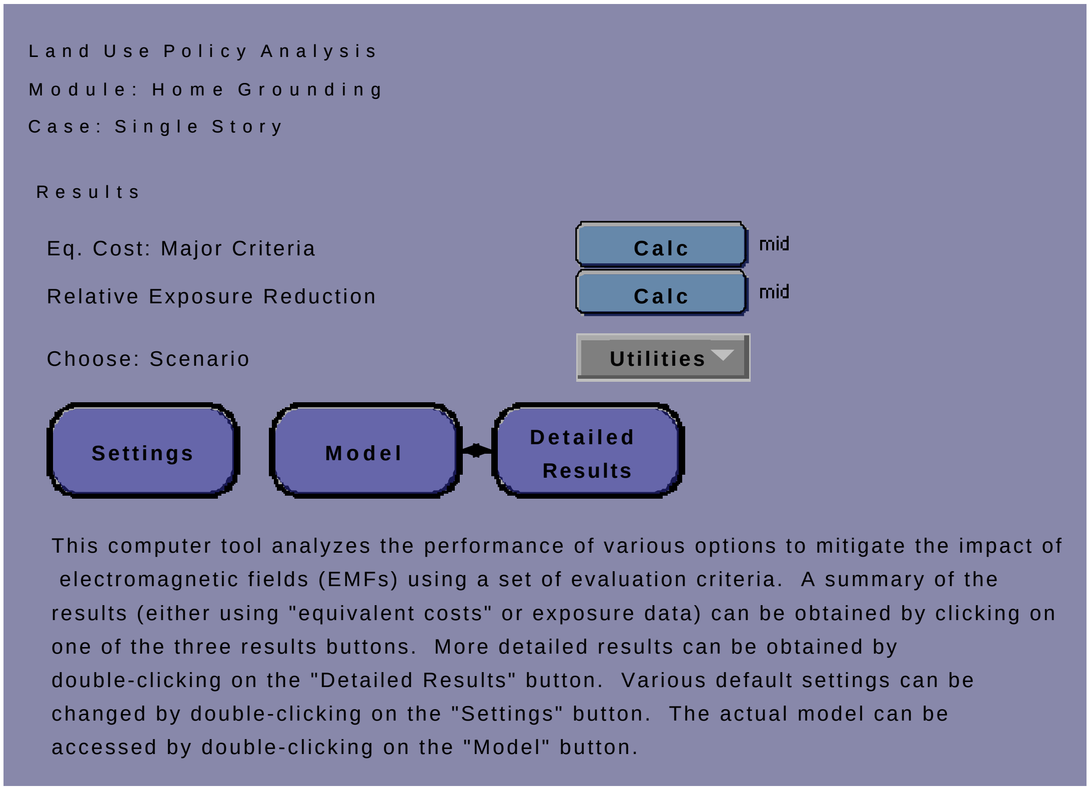
The default is 3 members in a household.

Part II: Home Grounding

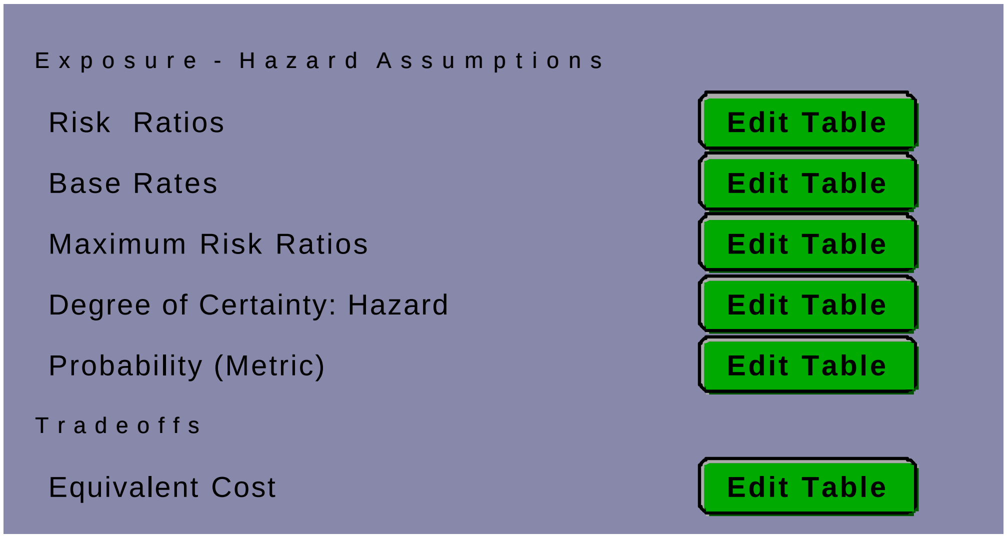
Introduction

This documentation describes the screens, key user variables, input parameters, and estimates for the Analytica models developed as part of the "Power Grid and Land Use Policy Analysis." The documentation follows the screen-shots of Analytica. The documentation can also be found in each Analytica model by clicking any node in the model and then clicking the question mark button at the top of the Analytica screen. This part only documents the parts of the model that are different from the transmission line and distribution line models. For other parts (e.g., risk ratios, base rates) the user is referred to part I.

The hardcopy of this documentation is for the "Home-A" Analytica model only. While the documentation is fairly generic and most of the materials apply to all models, some specific items will differ between models.

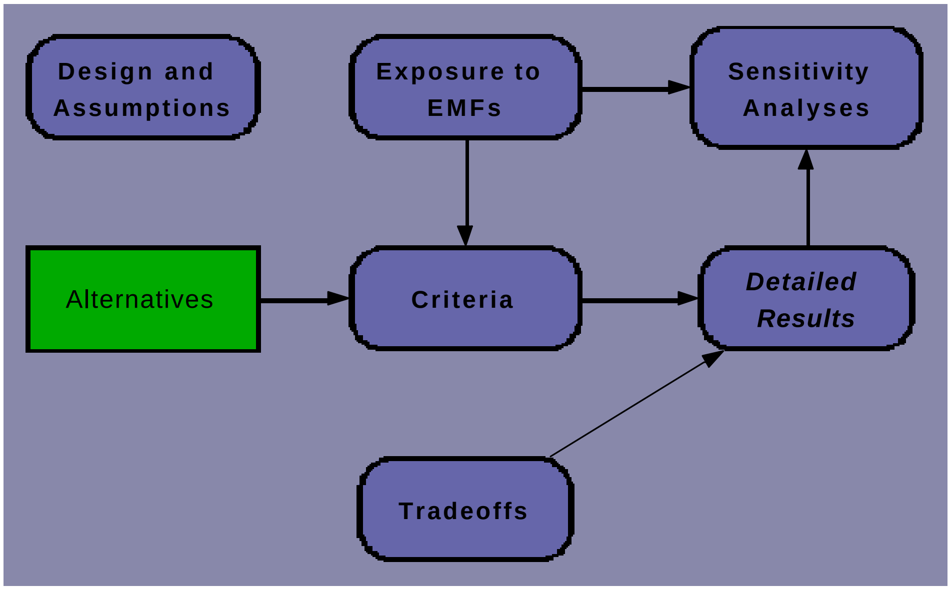

Land Use Policy Analysis
Module: Home Grounding
Case: Single Story
Results
Eq. Cost: Major Criteria
Calc
mid
Relative Exposure Reduction
Calc
mid
Choose: Scenario
Utilities
Settings
Model
Detailed Results
This computer tool analyzes the performance of various options to mitigate the impact of electromagnetic fields (EMFs) using a set of evaluation criteria. A summary of the results (either using "equivalent costs" or exposure data) can be obtained by clicking on one of the three results buttons. More detailed results can be obtained by double-clicking on the "Detailed Results" button. Various default settings can be changed by double-clicking on the "Settings" button. The actual model can be accessed by double-clicking on the "Model" button.

Settings



In the "Settings" menu, the user can make many changes to the key model parameters related to the potential EMF – Health link and tradeoffs.

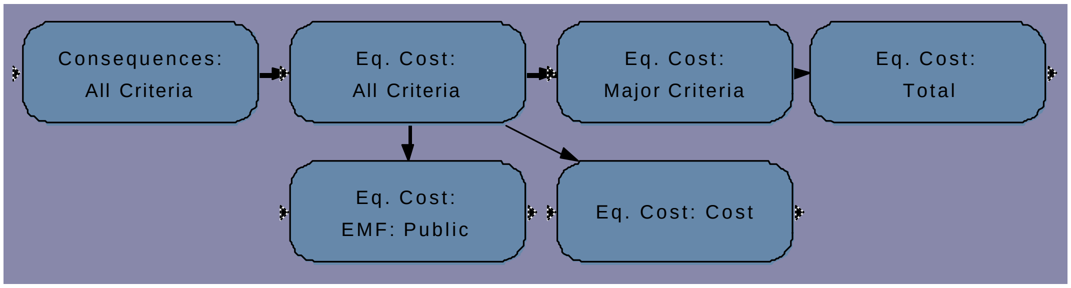
Model



Each Power Grid and Land Use Policy Analysis has the following building blocks: "Exposure to EMFs," "Alternatives," and "Criteria." In addition, "Design and Assumptions" and "Tradeoffs" are defined to produce "Detailed Results." The exposure data are imported from a model developed in C++ by Jack Adams (see Decision Insights, Inc., 1999). The "Alternatives" are evaluated on the "Criteria," for example on public health risks due to EMF or on total project cost. To evaluate the alternatives on the criteria, models are used, which are sometimes quite complex. To access the models, the user can double-click on the "Criteria" node and continue through the relevant sub-menus. The "Design and Assumptions" node contains a menu of basic inputs that define the mitigation alternatives as well as key parameters that are used throughout the model. The "Tradeoffs" are defined as unit equivalent costs for each criterion. For example the (default) tradeoff for one person-year life lost is $100,000. "Sensitivity Analyses" allow the user to vary the degree of certainty of a hazard and the risk ratios used in the model over a wide range to show how sensitive the decision is to variations in these parameters.

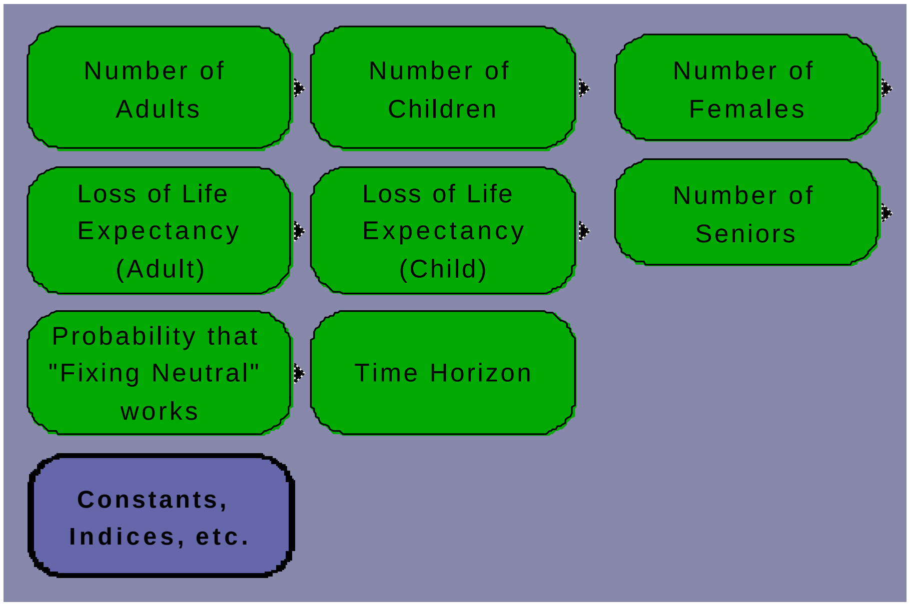
Decision Insights, Inc. Power Grid and Land Use Policy Analysis. DRAFT, April, 1999

Detailed Results



This diagram lets the user examine the results of the model at many different levels, ranging from the consequences, expressed in the natural units of the criteria ("Consequences: All Criteria") to various equivalent costs of subsets of the criteria and consequences. For example, the user can take a quick look at the "Eq. Cost: Major Criteria," which are public health and direct dollar costs. The equivalent costs are the consequences in their natural units multiplied by the unit equivalent cost defined in "Tradeoffs."

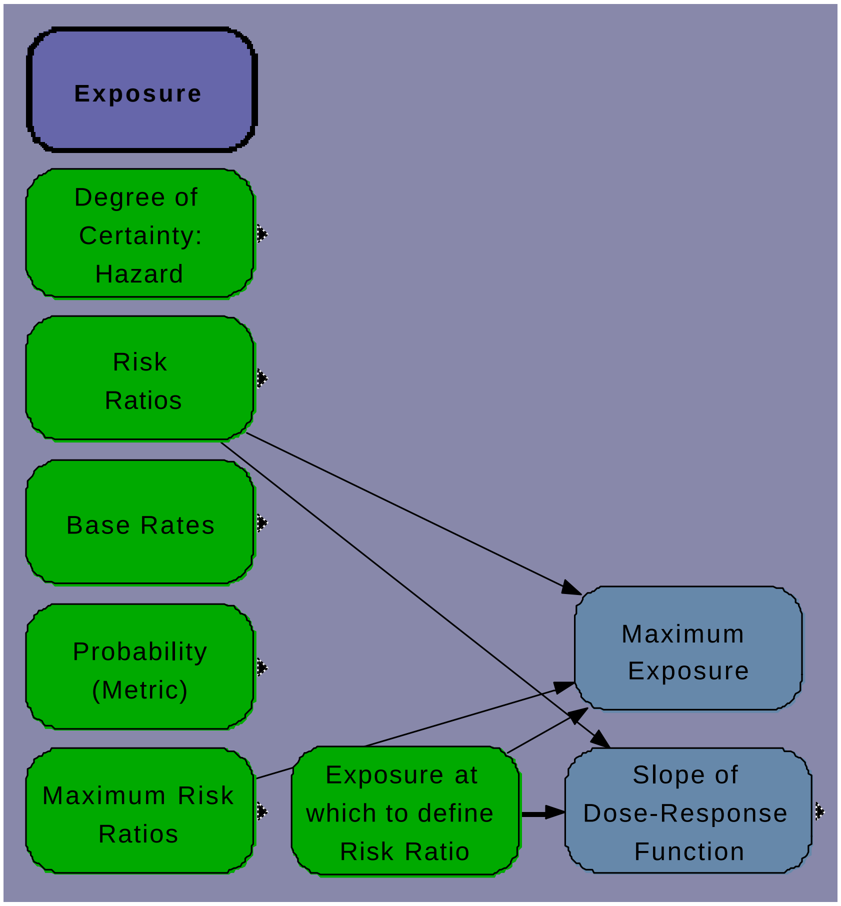
Model – Design and Assumptions



This menu lets the user specify several scenario parameters:

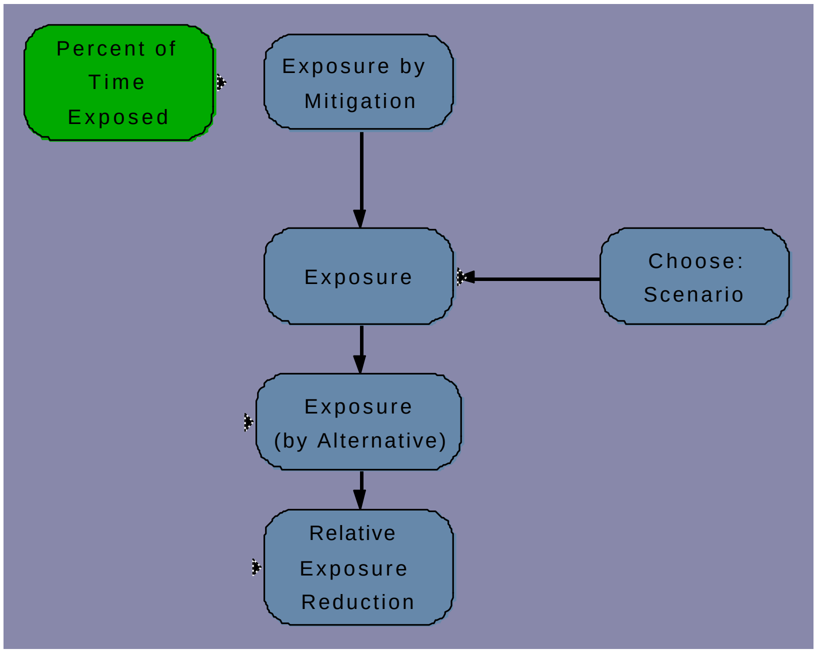
Number of adults in the home (default value: 2)
Number of children in the home (default value: 2)
Number of (adult) females in the home (default value: 1)
Number of seniors (above 65) in the home (default value: 0)
Loss of life expectancy (adult) (default value: 35)
Loss of life expectancy (child) (default value: 70)
Time horizon - the length of time that the family expects to live in the home (default value: 10 years)
Probability that "Fixing the Neutral" works - Fixing the neutral return is one of the alternatives in this model. If this fix eliminates the field, no additional work is done, otherwise the water pipe is insulated with a dielectric coupler. The default value for the probability that fixing the net return works is 0.70.

Model – Exposure to EMFs



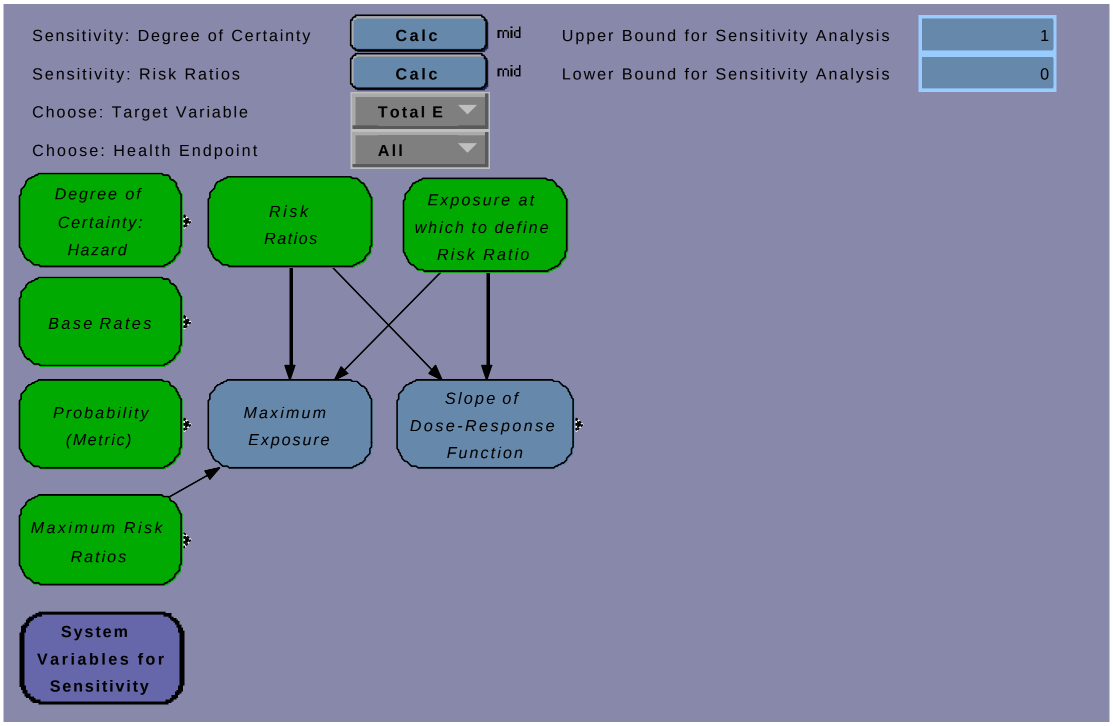
This model uses the inputs from the "Settings" menu to calculate the dose response function that is used to link exposures to risk.

Model –- Exposure to EMFs - Exposure



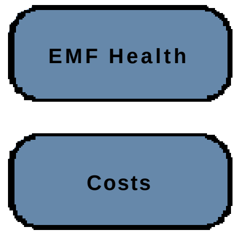
This model uses the exposure data obtained from Jack Adam's C+++ exposure model (see Decision insights, Inc. 1999) and the time people spend in the home to determine exposures (for different mitigation alternatives) and the relative exposure reduction. The exposure calculations are based on scenarios which describe the layout of the home and the location of the water pipe and service drop.

Model – Sensitivity Analyses



This menu lets the user access sensitivity analyses on the "Degree of Certainty: Hazard" and on the "Risk Ratios" for different health endpoints and different target variables. Other sensitive parameters like the "Probability (Metric)" or the "Maximum Risk Ratios" can be varied as well in this menu.

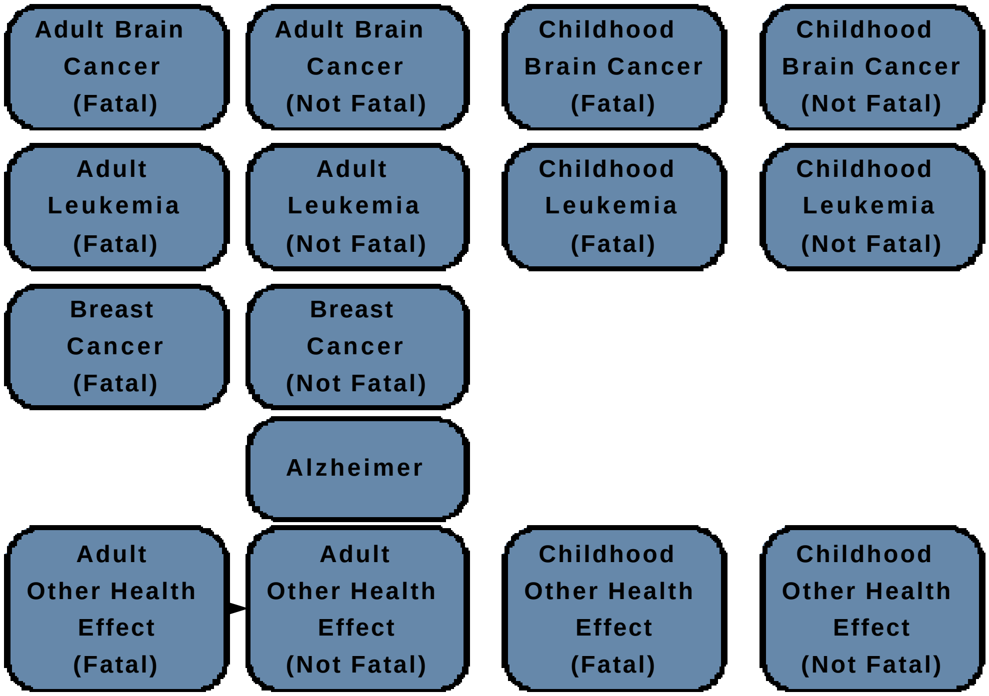
Model – Criteria



The home grounding model only has two decision criteria:

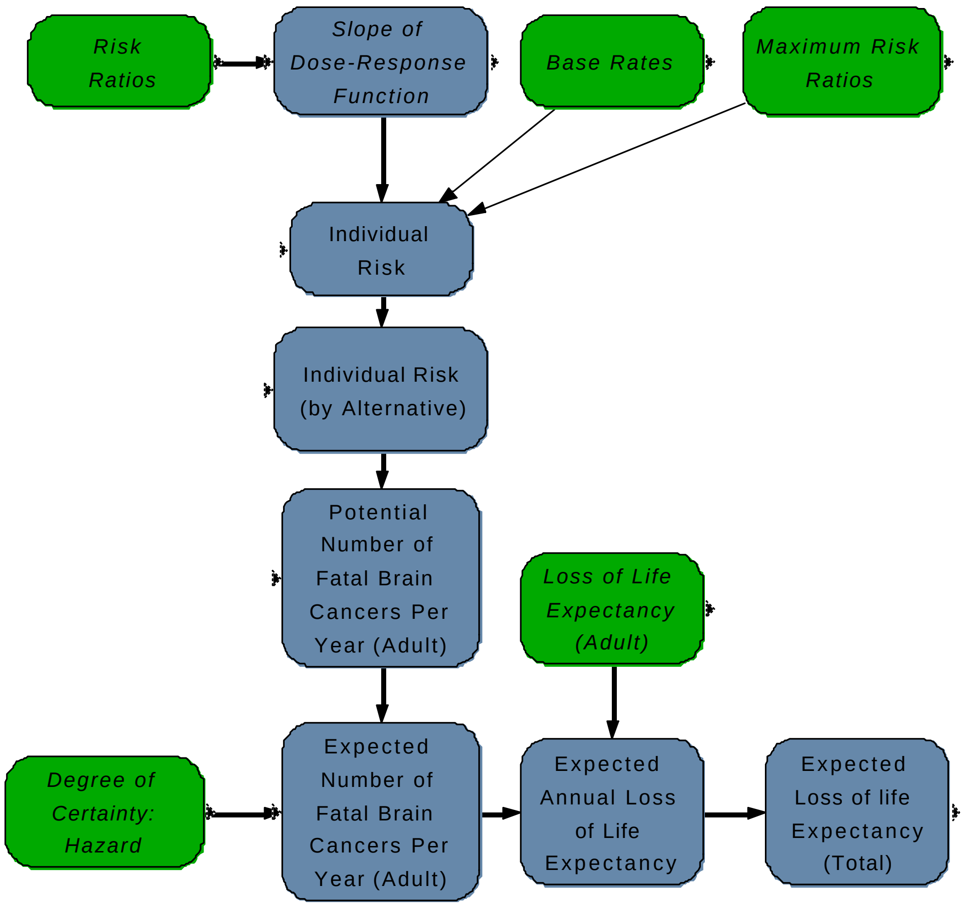
1. To minimize EMF health risks
2. To minimize costs of mitigation

Model – Criteria – EMF Health



The criterion "EMF Health" is divided into 15 sub-criteria. Key distinctions are the health endpoints (leukemia, brain cancer, breast cancer, and Alzheimer's disease), fatal vs. non-fatal health effects for cancers, and whether children or adults are affected. Alzheimer's disease is counted and evaluated as a long-term disease, not as a one-time cause of death. In addition, the user can supply the information for an unspecified health endpoint by using the four nodes for fatal and non-fatal "Other Health Effects" for children and adults. The health risk models are very similar across these health endpoints, as illustrated for the criterion "Adult Brain Cancer (Fatal)."

Model – Criteria – EMF Health – Adult Brain Cancer (Fatal)



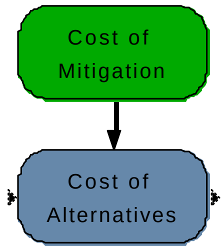
This diagram shows how the "Expected Loss of Life Expectancy (Total)" is calculated. The "Risk Ratios" and "Maximum Risk Ratios" are used to create dose-response functions, separately for each health endpoint. This is done as follows. The user inputs "Risk Ratios" that characterize, separately for each health endpoint, the increase in risk at 2mG (or equivalent "medium" exposure for other metrics), assuming that EMF is a hazard. This input defines one point of the dose-response function. The other point is defined by a risk ratio of 1 at zero mG exposure (or 0% exceedances of a threshold). From this information, the model calculates the slope of a linear dose-response function (the intercept being at RR=1, Exposure=0). The user also specifies the "Maximum Risk Ratio," which is defined as the maximum factor by which risk can plausibly be increased, if one assumes that EMF is a hazard. This input provides an upper limit for the risk ratios and defines an exposure, above which the risk ratio is held constant at its upper limit.

Using the input from Jack Adams' exposure model, the "Slope of the Dose-Response Function," and the "Base Rates" for each health endpoint, the model then calculates "Individual Risk" in terms of annual fatality or illness rate. This individual risk is multiplied by the number of people exposed to determine the "Potential Number of Fatal (or Nonfatal) Cancers per Year," separately for Adults and Children, assuming that there is a hazard. The "Expected Number of Fatal (or Nonfatal) Cancers per Year" are then calculated by multiplying the "Potential Number of Fatal (or Nonfatal) Cancers per Year" by the "Degree of Certainty: Hazard," which specifies the probability that EMF exposure poses a hazard. In the case of Alzheimer's disease, the model considers only the incidence rate and calculates the "Expected Number of Annual Alzheimer Cases."

For fatal cancers, the "Expected Number of Fatal Cancers" are multiplied with the average "Loss of Life Expectancy" to determine an "Expected Annual Loss of Life Expectancy." This annual loss is multiplied by the time horizon of the model (default: 10 years) to calculate the "Expected Loss of Life Expectancy (Total)".

For nonfatal cancers, the "Expected Number of Non-Fatal Cancers Per Year" are multiplied by the time horizon of the model (default: 10 years) to calculate the "Expected Number of Nonfatal Cancers (Total)." Alzheimer's disease is treated like a non-fatal cancer.

Model – Criteria - Costs

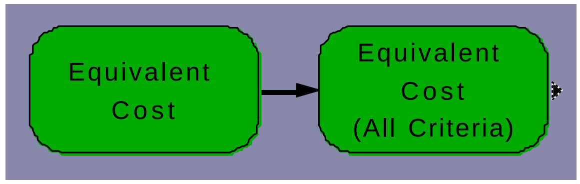


This menu lets the user edit the costs of the following alternatives. The default values were adapted from von Winterfeldt and Trauger (1996).

1. Fixing the net return (default value: $105)
2. Fixing the net return, then insulating the water pipe (default value: $315)
3. Insulating the water pipe (default value: $210)
4. Changing the living arrangements (default value: $50)

Von Winterfeldt, D. and Trauger, T. Managing electromagnetic fields from residential electrode grounding systems. *Bioelectromagnetics, 17*, 71-84.

Model - Tradeoffs



Equivalent cost tradeoffs are defined for units of all criteria in the model, in order to make the consequences on different criteria commensurable.

The literature on the value of life and injuries was used to define default values (see, for example, Jones-Lee, 1976; Thaler and Rosen, 1975; Howard, 1980; Viscusi, 1992, 1993; Tengs, 1995). In addition, a recent interview with five national researchers familiar with the risk tradeoff literature (Keeney and von Winterfeldt, 1997) was used to calibrate the tradeoffs. Other values were estimated based on common sense reasoning. The default values are:

One Year of Life-Expectancy Lost: $100,000
One Non-Fatal Cancer (Adult): $300,000
One Non-Fatal Cancer (Child): $500,000
One Alzheimer's Disease: $200,000

Jones-Lee, M.W. The value of life: An economic analysis. Chicago: Chicago University Press, 1976.

Howard, R. On making life and death decisions. In R.C. Schwing and W.R. Alberts (eds.) Societal risk assessment. New York, Plenum Press, 1980, 89-106.

Tengs, T., et al. Five hundred life-savings intervention and their cost-effectiveness. Risk Analysis, 15, 3, 1995, 369-390.

Thaler, R. and Rosen, S. The value of saving a life: Evidence from the labor market. In Terleckyi, N.E. (ed.) Household production and consumption. New York: Columbia University Press, 1975, 265-298.

Viscusi, W,K. Fatal tradeoffs. New York: Oxford University Press, 1992.

Viscusi, W.K. The value of risks to life and health. Journal of Economic Literature, 312, 1993, 1912-1946.

Keeney, R.L. and von Winterfeldt, D. Value tradeoffs for the Hanford tank waste remediation system program. Report No. PNNL-11724, UC-630. Ricjland, WA: Pacific Northwest National Laboratory, 1997.

Model – Alternatives

The following alternatives are considered:

1. Base case (do nothing)
2. Insert dielectric coupler into the water pipe
3. Fix neutral - if it works, stop; if it does not work, insert a dielectric coupler into the water pipe
5. Change living arrangements